

Summary Report

1970-1977

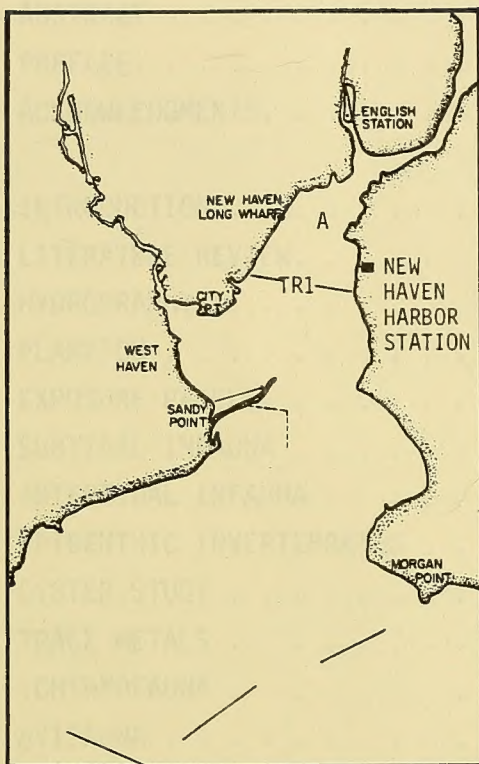
Prepared for
The United Illuminating Company
New Haven, Connecticut

New Haven
Harbor
Ecological
Studies
1979



Normandeau
Associates, Inc.

AVPT
MSI
TD
195
E4
N67
1979



New Haven Harbor Ecological Studies Summary Report 1970-1977

Prepared for
The United Illuminating Company
New Haven, Connecticut

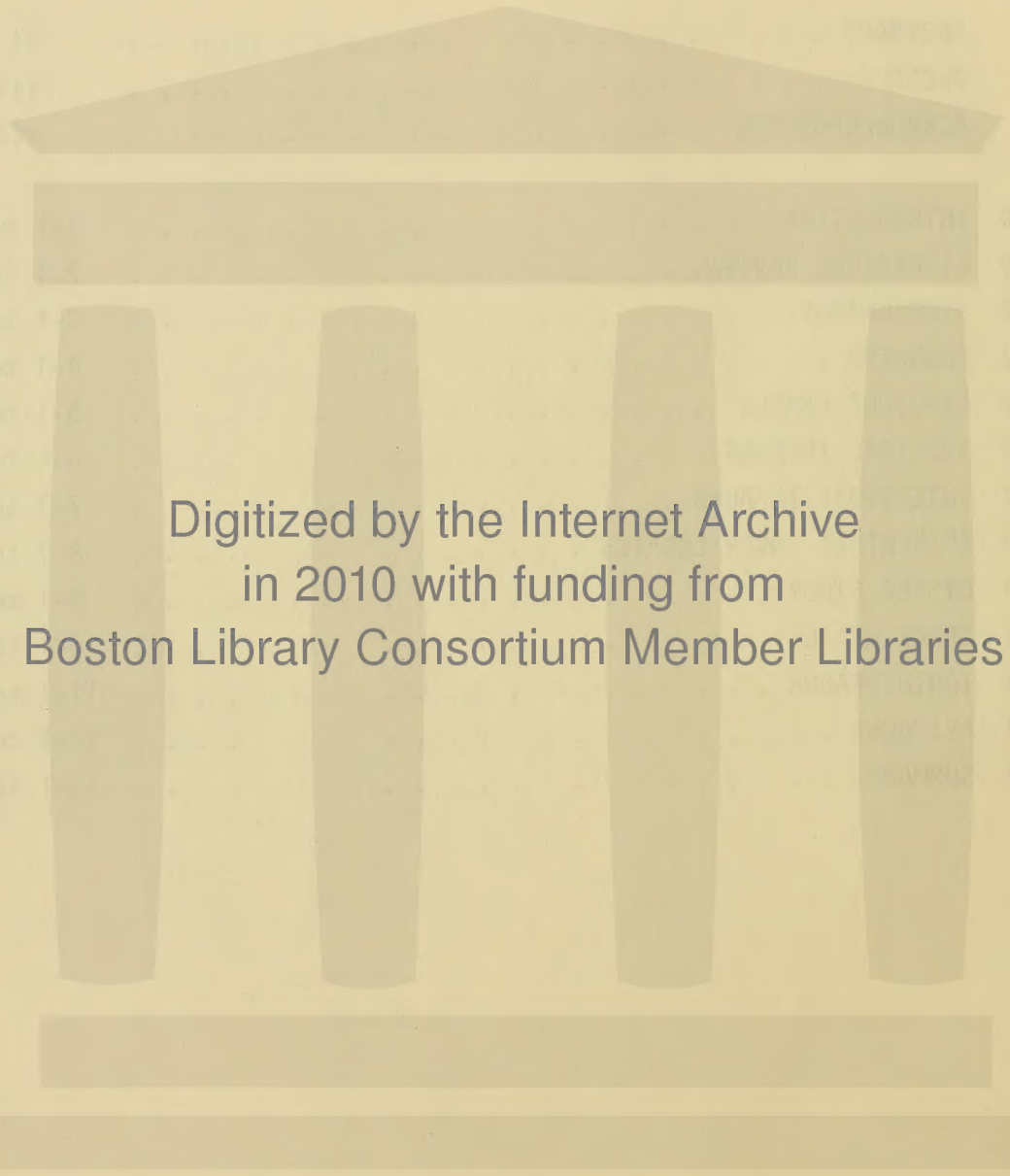
by
Normandeau Associates, Inc.
Bedford, New Hampshire

Edited by
Andrew J. McCusker
Weldon S. Bosworth, Ph.D.

April 1979

TABLE OF CONTENTS

	PAGE
ABSTRACT	ii
PREFACE.	iii - vi
ACKNOWLEDGMENTS.	vii - ix
 1.0 INTRODUCTION	 1-1 to 1-24
2.0 LITERATURE REVIEW.	2-1 to 2-31
3.0 HYDROGRAPHY.	3-1 to 3-107
4.0 PLANKTON	4-1 to 4-94
5.0 EXPOSURE PANELS.	5-1 to 5-53
6.0 SUBTIDAL INFAUNA	6-1 to 6-64
7.0 INTERTIDAL INFAUNA	7-1 to 7-30
8.0 EPIBENTHIC INVERTEBRATES	8-1 to 8-49
9.0 OYSTER STUDY	9-1 to 9-37
10.0 TRACE METALS	10-1 to 10-44
11.0 ICHTHYOFAUNA	11-1 to 11-123
12.0 AVIFAUNA	12-1 to 12-54
13.0 SUMMARY.	13-1 to 13-26



Digitized by the Internet Archive
in 2010 with funding from
Boston Library Consortium Member Libraries

ABSTRACT

The New Haven Harbor (Connecticut) Ecological Studies Summary Report presents results from a seven-year monitoring program and analyzes possible impacts of United Illuminating Company's 460 MW oil-fired electric generating station on harbor biota. The report fulfills an NPDES discharge permit requirement and, in addition, is designed to maximize usefulness of the data base to other researchers. Individual report sections are presented to characterize New Haven Harbor and analyze plant impacts on: Hydrography, Plankton, Exposure Panels, Subtidal Infauna, Epibenthic Invertebrates, Oyster Growth, Trace Metals, Ichthyofauna and Avifauna.

Hydrographic studies characterized in New Haven Harbor as a temperate estuary defined by predictable seasonal changes in physical and chemical water parameters that are primarily regulated by temperature and precipitation. The hydrographic regime in proximity to the plant is altered by operation of the plant's condenser cooling system which draws in harbor water through a shoreline intake structure at 625 cfs and discharges subaqueously near the shipping channel (700' from shore) at a design ΔT of 8.3°C (15°F). Effects of cooling system operation on the current regime were restricted to small areas adjacent to intake and discharge structures, and effects on heavy metal concentrations or dissolved gases were inconsequential. As determined by mathematical modeling, the thermal plume from the plant was buoyant for most salinity-temperature conditions. Aerial infrared imagery and thermal/dye studies showed the surface extent of the plume to be limited - area bounded by the isotherm 2°F ΔT was less than 0.6% of the inner harbor surface area.

Biological parameters in New Haven Harbor, including species richness, abundance and spatial distribution, fluctuated widely from year to year, but overall, most species assemblages could be characterized by somewhat predictable, seasonal trends, similar to those observed in other Long Island Sound harbors. Each biological assemblage was generally characterized by a group of numerically and temporally dominant species over the duration of the study. Though abundances and occurrence of these dominants varied substantially, most dominant species showed predictable seasonal patterns in presence/absence, abundances and spatial utilization of the harbor.

Mechanisms of plant impact on the harbor addressed in this report include impingement of epibenthic invertebrates and finfish, plankton entrainment through the cooling water system, effects of altered current patterns associated with the intake and discharge structures, possible changes in dissolved gases and contact of organisms with the thermal plume. The small size buoyant nature, and dynamics of the plume minimize its potential to impact the harbor biota, consequently impingement on the traveling screens and entrainment through the cooling system were determined to be the most important potential modes of plant effect on the biota. Impacts were analyzed by comparing the two years of operational data with the range of values observed during the five preoperational years. Several species showed distributional or abundance changes, but were either 1) local changes not in proximity to the plant; 2) harborwide and not restricted to the area of the plant; or 3) not coincident with plant impact.

The overall conclusion from comparison of preoperational and operational periods for all assemblages monitored with respect to species composition, abundance, diversity, and spatial and temporal distribution was that the plant had no discernible impact on the biota of New Haven Harbor.

PREFACE

As one who had a hand on the throttle of the Connecticut River Ecological Study (Merriman and Thorpe, 1976), it has been a privilege for me to examine this work on New Haven Harbor.

Both studies have dealt with the same problem: namely, the effects on the aquatic ecosystem of the operation of a once-through condenser-cooling complex as employed by an electricity-generating station. These effects may be of two sorts: first, those resulting from the impact of the thermal effluent emanating from the plant; and second, those involving either the impingement of fish and other organisms on the intake screen or the entrainment of the smaller elements of the biota that are sucked through the screen and pass through the system.

For the purpose of discussion here, it matters not at all that one power plant, Connecticut Yankee (CY), is nuclear while the other, New Haven Harbor Station (NHHS), is oil-fired. Fundamentally, we are concerned with thermal and associated effects - i.e., what are the impacts, potential or real, on the assemblage of plants and animals in the affected area?

Apart from the basic nature of the problem, the two studies have certain other features in common. As the cros flies, the plants are only 25 miles apart, so that in general they are subject to much the same meteorological and seasonal vicissitudes. Both discharge their waste heat into relatively large, though partially circumscribed, areas of water that are characterized by a substantial amount of movement. The one (CY) discharges its water at a rate of some 825 cubic feet per second approximately 20° Fahrenheit warmer than when it was withdrawn from the river 90 seconds earlier; the other (NHHS) operates its cooling system at a rate of 625 cfs with a temperature increase of 15°F.

At this point the gross features of the two studies become sharply divergent. The one is essentially a riverine situation where, though subject to major tidal effects, there is no salinity and the down-stream flow of fresh water is predominant. This contrasts with the present study that deals with an estuarine zone in which the saline waters of Long Island Sound prevail over the relatively small runoff from several rivers and in which the tidal flow is by far the most influential. As a result, not only are the hydrographic conditions vastly different but the flora and fauna, with only minor overlap, are wholly distinct from those of the Connecticut Yankee situation. It is precisely these sorts of differences that led Bell (1971) and others to point out the fallacy in making universal regulations governing thermal discharges without regard for the conditions peculiar to each plant site. Furthermore, the methods of discharge of the heated effluent from the two plants are radically different so that the respective impacts of each body of

warmed water on their related ecosystems are in no way comparable, although in fact each gives every evidence of being admirably suited to its particular situation.

It is not surprising therefore that the overall direction and content of these two studies, riverine and estuarine, are singularly different. With Connecticut Yankee there was the possibility that the thermal discharge might completely block the passage of valuable anadromous fish such as shad to their spawning grounds and thus eliminate the species from the river in much the same way that salmon were eradicated by dams at the turn into the 19th century. For this reason, and perhaps also because of the predilection of the CY study staff and directors, some two-thirds of the published report on this study is devoted to fishes (Coutant, 1977). The present work on New Haven Harbor offers a much more balanced treatment of the ecology of the region and related matters. It is also comprehensive, both as to subject matter and detail. For example, apart from the scenarios on plankton, benthos and fishes, there are separate sections on oysters, avifauna, trace metals, etc. As for detail, unusually high numbers of different kinds of organisms were encountered in this work - e.g., over 300 benthic forms in New Haven Harbor. In short, the New Haven Harbor Study is an exhaustive presentation that fully documents the ecology of the estuary and provides a solid basis for future comparison.

In the consideration of these two studies, there is another matter that needs mention. The Connecticut River study was blessed with a remarkable continuity of staff and methodology from its inception in 1965 to its completion nine years later. Moreover, its scientific personnel were permanently located in the Essex Marine Laboratory with immediate access to the study area, and this in turn led to the fact that the authors of the summary monograph were all directly involved in the field work from start to finish. The New Haven Harbor study, 1970-1977, was not as fortunate in these several regards. As a consequence a number of additional problems had to be addressed, particularly in interpreting the results of changes in sampling methodology. Let it be said, however, that this Summary Report is meticulous and circumspect in its treatment of the data involved. I raise the subject to emphasize two points: first, that in studies of this sort the initial design of the field work and its consistency are directly related to the success of the project and the return on the investment; and second, that the overall conclusions in this report are in no way impaired by the above-mentioned circumstances.

The stated purposes of the New Haven Harbor Ecological Studies (Introduction, p, 1-2) were to "evaluate possible impacts of the generating station on the harbor ecosystem," and "to describe the ecology of New Haven Harbor." This Summary Report indicates at every turn that there appear to be no adverse environmental effects of any consequence. As to the descriptive ecology, I have already spoken of its detail and scope, and a glance at the various Tables of Contents of the individual sections will bear me out. The information on the fauna and flora that is contained in this report can be looked upon as a sort of data bank, and as such it is extremely valuable. Moreover, as indicated throughout this volume, there

are similar accumulations of available data from other areas on both the north and south shores of Long Island Sound. There is also unpublished material (e.g., Rhoads on the benthic fauna of the Sound, personal communication) as well as information scattered through the more formal published literature. It occurs to me that from all these sources it would be possible for some interested party to put together a definitive documented inventory of the fauna and flora of Long Island Sound. Such a volume on this distinctive and most important body of water would be of enormous scientific and practical use - a modern counterpart, if you like, of the early classic by Sumner, Osburn, and Cole (1913), "A Biological Survey of the Waters of Woods Hole and Vicinity."

Let me here turn to a subject of broader dimensions. The New Haven Harbor Station Ecological Studies have amply fulfilled the requirements embodied in the various federal pollution control and environmental policy acts and amendments as they developed before and during the course of the investigation here reported. Furthermore, as indicated above, there is also now available a wealth of ecological information on a number of other specific areas on the Long Island Sound shoreline; these base-line data are the outcome of intensive scrutiny under the same regulations that dictated the present study. In this regard we owe much to the movement that led to the requirements for detailed examination of localities where there was the potential for "thermal pollution" - the popular and often intemperate terminology that had its origin with the development of nuclear power in the utility business. Now, it seems to me, it is appropriate that the public in Connecticut and New York be made aware of the thorough nature of these environmental monitoring studies, which, it should be noted, have been conducted at enormous expense. Uninformed and unbridled public pressure on regulatory agencies might thereby be modified. What is needed at this stage is more flexibility in the regulatory processes, especially with an eye to the time requirements that so impede our progress toward a reasonable degree of energy independence. I believe that in the present state of our assembled knowledge of Long Island Sound we are now in a position to take positive steps in this direction.

Like so many others, I worry in the broader context about the entangling regulatory web now plaguing us in so many walks of life; it can be a debilitating and stultifying process, pernicious in the long run. The need for such straight-laced canon clearly comes under question in all fields of scientific and technological endeavor. Its reductio ad absurdum in the field of medicine is illustrated by penicillin. If this wonder drug, introduced 40 years ago, were discovered today the chances are that it "...would not pass the extensive animal research tests that are a prerequisite to marketing" (Altman, 1979). A different example of the stifling effect imposed by present federal regulatory policy is that of the system of grant and contract proposals for research support - particularly as it applies to the academic community. Thus Leopold (1970) estimates that last year some 2700 man-years were invested in proposal writing, and suggests that we may be approaching the fanciful situation alluded to a decade and a half ago where if "...some group should ever want to bring research progress to a standstill, they could do so by establishing a competitive grant system under which all researchers would be required to prepare written proposals describing what they wished

to work on." And in a similar vein, relating to the mounting bureaucratic red tape, an eminent professor of biology at Yale was recently quoted as saying that paperwork "wouldn't have to go much farther and I'd say it wasn't worth it."

No one will argue against the need for reasonable regulation at federal, state, or municipal levels; but overdone, it more than defeats its purpose - it strangles. This applies to environmental affairs just as much as it does in the examples cited above.

This New Haven Harbor Summary Report can thus be viewed in a dual capacity. It has accomplished its aims of evaluating possible impacts and describing the local ecology with a high level of scientific proficiency and integrity. It is also an instrument that may be used by example to bring about tractable regulation that will allow us to get on more effectively with the necessary and vital conduct of our energy affairs without unreasonable disruption of the environment.

Daniel Merriman
8 March 1979

REFERENCES CITED

- Altman, L. K. 1979. Why penicillin continues to grow in importance. N.Y. Times, Feb. 6 (C):1-2.
- Bell, W. H. 1971. Thermal effluents from electrical power generation. Fish. Res. Board Can., Tech. Rep. 262. 54 pp.
- Coutant, C. C. 1977. Reviews. Trans. Am. Fish. Soc. 106(1):115-116.
- Duxbury, A. C. 1963. A hydrographic survey of New Haven Harbor 1962-1963. Conn. Water Resources Bull. No. 3A: 19 pp., with 2 Appendices and 66 Figs.
- Leopold, A. C. 1979. The burden of competitive grants. Science 203 (4381):607.
- Merriman, D., and L. M. Thorpe. 1976. The Connecticut River ecological study: the impact of a nuclear power plant. Am. Fish. Soc., Monograph No. 1: xi+252 pp.
- Sumner, F. B., R. C. Osburn, and L. J. Cole. 1913. A biological survey of the waters of Woods Hole and vicinity. Part II, section III: A catalogue of the marine fauna. Bull. U. S. Bur. Fisheries, XXXI(II): 549-794.

ACKNOWLEDGMENTS

An effort such as the studies assembled into this report, encompassing many years and different contracting companies and individuals, obviously required the efforts of many individuals quite aside from those of the various authors.

We would like to here acknowledge the efforts of those who have contributed most importantly and most recently to the study program and the report. Field and laboratory personnel who participated in the data acquisition process are listed, along with their respective roles, at the end of this section.

Program Development and Early Years

The formative years - early program guidance, environmental impact analysis and inclusion of mitigative measures - were largely guided by John Davis of Normandeau Associates, Inc. (NAI). Certain technical program elements and overall review and guidance were provided by Gordon A. Riley and Peter J. Wangersky of Dalhousie University, Halifax, Nova Scotia, and Karl Turekian, Robert Gordon, Robert Berner and Donald Rhoads of Yale University. Important ideas and recommendations were contributed by many other concerned individuals and scientists. The major efforts of United Illuminating Co. (UI) project manager Richard Grossi, with the nearly full-time efforts of William Wakefield, project engineer - civil and permits, and their commitment to full consideration of environmental concerns were vital.

From the last stages of construction, Marcus McCraven, now Vice President-Environmental Engineering, and David Damer, certainly the most biologically perceptive mechanical engineer we know, kept close contact with the program through hard questioning and continued involvement in maintaining an effective and fully responsive environmental program.

Mr. Wadsworth Owen of the University of Delaware directed 1976 dye and thermal surveys to define the plant's thermal plume.

Data Acquisition

Collection and analysis of most of the data utilized in this report was completed by the W. F. Clapp Laboratories of the Battelle Memorial Institute, Duxbury, MA (1971-1975) and by Marine Research, Inc., Falmouth, MA (1975-1977). Robert Hillman, and later Charles Willingham, were responsible for Battelle's efforts with a capable Edward C. (Ned) Kelly directly supervising both field and laboratory efforts.

Alexander Beichek was in charge of the Marine Research, Inc. effort. Specific program data acquisition responsibilities were shared by Richard

Toner (zooplankton and phytoplankton), Michael Scherer (ichthyoplankton), Kris Swanson (benthic invertebrates), Donald Bourne (finfish), and John Garey (hydrographic). Field efforts were under the effective direction of James Fox and Derek MacDonald.

The Report

We can say no more of the editorial review of Daniel Merriman, Professor emeritus of Yale University, and David Damer, Environmental Engineer for UI than that they offered countless suggestions on the papers and that we found them constructive to the point that we made adjustments in response to nearly all of them. Professor Merriman's perspectives on the presentation of scientific data, his understanding of power plant impacts, and his skill as an editor were invaluable. Mr. Damer's clarity of perspective and demand for clarity in writing have hopefully guided us to produce a report that can be read and understood by the non-ecologist as well as the discipline specialist.

Many whose names appear as authors of various papers contributed substantially more to the total report than in writing the individual sections. Particularly intensive and extensive were efforts by David Pease, Paul Ferreira and Drew Harvell, all of NAI. Unheralded, critically needed assistance on data manipulation and analysis came from NAI scientific programmer, Richard Ploss and statistician, Ronna LaPenn. Jon Witman assisted in preliminary analysis of benthic data.

Finally, we commend for an excellent job in the face of numerous revisions (we won't say how many) and a heavy work load of technical typing - Jane Bieniek, Judith Eaton and Elissa Cusumano, and for publications work, Fred Silsby and Ann Lemay. John Fay, head of NAI's publications, proofed all final drafts in addition to supervising the publication effort. Theresa Carpentieri of UI guided final publications efforts.

NEW HAVEN ECOLOGICAL MONITORING STUDIES
FIELD AND LABORATORY PERSONNEL, 1971-1977

Name

<u>Field</u>	<u>Company</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>
Charles Willingham	CL/B	x	x					
Jay Wennemer	CL/B	x	x	x				
Edward Butler	CL/B	x	x	x	x	x	x	
Sandy Archibald	CL/B	x	x	x				
Edward Kelly	CL/B		x	x	x	x	x	
John Williams	CL/B			x	x	x	x	
F. William Driver	CL/B			x	x	x	x	
Herbert Howland	CL/B			x	x	x		
James Fox	MRI						x	x
Derek MacDonald	MRI							x
Kris Swanson	MRI						x	x
Joth Davis	MRI							x
George Wheelwright	MRI						x	x
Arnold Rosengren	MRI							x
Diane Ciaccio	MRI							x
Armand Hamel	MRI						x	x
Rose Petrecca	MRI							x

Laboratory

Company

Benthos

Bea Richards	CL/B	x	x	x	x	x	x	
Edward Butler	CL/B	x	x					
Edward Kelly	CL/B		x	x	x	x	x	
Ellen Price	CL/B	x	x	x	x	x		
Kris Swanson	MRI						x	x
Rose Petrecca	MRI							x

Finfish

Jay Wennemer	CL/B	x	x	x				
Edward Kelly	CL/B		x	x	x	x	x	
James Fox	MRI						x	
Derek MacDonald	MRI						x	x

Plankton

Paul Batson	CL/B	x	x	x	x			
John Williams	CL/B			x	x	x	x	
Marc Stuart	CL/B				x	x	x	
F. William Driver	CL/B			x	x	x	x	
Jay Wennemer	CL/B	x	x	x				
Fred Tone	CL/B	x	x	x				
Theo Bugsch	CL/B			x	x			
Michael Scherer	MRI						x	
Barry Brooks	MRI						x	x
Armand Hamel	MRI						x	x
Leslie Fonger	MRI							x
Robert Silvia	MRI						x	x
Deborah Queen	MRI						x	x
Diane Thier	MRI						x	x
Diane Ciaccio	MRI							x
Elizabeth Sechoka	MRI							x
Terence Hayes	MRI							x

CL/B = Clapp Laboratories, Battelle

MRI = Marine Research, Inc.

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

1.0 INTRODUCTION

by Andrew J. McCusker and John D. Davis
Normandeau Associates, Inc.
Bedford, N. H.

TABLE OF CONTENTS

	PAGE
<i>INTRODUCTION.</i>	<i>1-1</i>
<i>General Description of New Haven Harbor</i>	<i>1-3</i>
<i>Harbor Usage.</i>	<i>1-7</i>
<i>New Haven Harbor Station.</i>	<i>1-8</i>
<i>Cooling Water</i>	<i>1-11</i>
<i>Drainage and Sanitary Wastes.</i>	<i>1-12</i>
<i>Siting and Related Studies.</i>	<i>1-14</i>
<i>Monitoring Studies Program.</i>	<i>1-16</i>
<i>Literature Cited.</i>	<i>1-22</i>

LIST OF FIGURES

1-1. New Haven Harbor location map	1-4
1-2. Average hourly gross electrical generation (in MW) plotted by day for New Haven Harbor Station, 1975 through 1977.	1-9
1-3. Plot plan of New Haven Harbor Station generating plant. .	1-10
1-4. Plan of New Haven Harbor Station circulating water intake structure.	1-13

LIST OF TABLES

1-1. SUMMARY OF SAMPLING REGIME FOR NEW HAVEN HARBOR STATION ECOLOGICAL STUDIES AS IT EXISTED IN OCTOBER 1977.	1-20
---	------

1.0 INTRODUCTION

by Andrew J. McCusker and John D. Davis
Normandeau Associates, Inc.
Bedford, N. H.

New Haven Harbor Station, a 460-MW oil-fired electric generating station operated by The United Illuminating Company (UI), is located on the east shore of New Haven Harbor in New Haven, Connecticut. During normal operations, the plant interacts with the harbor in several ways. Through operation of a 625-cfs once-through cooling system, the plant adds waste heat to the harbor water at a rate of 2.1×10^9 BTU per hour with a design temperature increase (ΔT) of 15°F. The plant receives oil via barge approximately once a week. Additional interaction results from maintenance dredging of a channel leading to the intake structure and around the oil off-loading pier.

Planning for the New Haven Harbor Station began in 1970, construction in 1973, and commercial operations in August 1975. The overall process from planning through operations made the project subject to the Federal Water Pollution Control Act of 1969 and amendments of 1972 and 1977, the National Environmental Policy Act of 1972, and regulations pursuant to those acts. Relevant regulations included effluent standards and guidelines for the steam electric-power generating point-source category promulgated in October 1974 as well as the 316a and 316b draft guidelines also first issued in 1974. In September 1973, the State of Connecticut received approval from the Administrator of the U.S. Environmental Protection Agency to administer the NPDES program through its Department of Environmental Protection. Under this evolving framework of regulators and regulations, studies were conducted to evaluate potential environmental impacts, to aid development of recommendations for mitigative design measures, and to monitor environmental effects of construction and operation of the facility.

During planning and construction phases, the U.S. Army Corps of Engineers (ACE) was the lead federal agency, and in 1972 prepared an

Environmental Impact Statement. Construction permits were granted and in October 1973 an NPDES permit was issued by the Connecticut DEP, authorizing operation of the facility through June 1977 and specifying monitoring and reporting requirements as well as discharge limitations and criteria. The subsequent NPDES permit, effective June 30, 1977, stipulated that UI:

...submit to the Commissioner a summary report concerning all biological monitoring studies. Such a report shall address the relationship of monitoring data collected after station start-up to baseline data collected prior to station operation.

It is in response to this requirement that this summary report is presented.

The format and general approach to the summary report is intended to maximize the utility of the data collected for the United Illuminating-sponsored environmental study programs, both with regard to provisions of the permit requirement and to the scientific community. The basic format reflects consideration of The Connecticut River Ecological Study monograph (Merriman and Thorpe, 1976) which summarized nine years of monitoring data and special studies related to the Connecticut Yankee Haddam Neck nuclear plant. The two efforts are similar in application of multi-year monitoring program data to consider impacts largely related to impingement, entrainment and thermal addition; however, they differ significantly in program structure and content.

The objectives of the New Haven Harbor Ecological Studies Summary Report are twofold: first, to describe the ecology of New Haven Harbor; and second, to identify and evaluate possible impacts of the generating station on the harbor ecosystem. There has been no previous comprehensive ecological study of New Haven Harbor with which comparisons can be made. Incorporated into the data base for this report are results of UI-sponsored programs, including preoperational and opera-

tional monitoring studies and studies performed for special purposes, as well as data available from other sources which are pertinent to New Haven Harbor. These latter include data from greater Long Island Sound and other estuaries in the general area, and they provide the perspective with which to relate the biological, physical and chemical structure of New Haven Harbor to the larger Long Island Sound ecosystem.

Most of the program papers in this report are made up of two major sections; the first characterizes New Haven Harbor in relation to the specific program; the second addresses the potential and observed impacts of New Haven Harbor Station operation on the harbor. Physical-chemical water quality and biological parameters in New Haven Harbor are characterized with emphasis on annual, seasonal and distributional trends. The relationship between the New Haven Harbor ecosystem and that of Long Island Sound and other harbors on the Sound is considered by comparison with historical and concurrent data. In the "impact" sections, potential mechanisms by which the plant might have an effect are identified and consideration is given to how these impacts might be detected through the available data. Preoperational and operational data are evaluated for observable plant impacts, and effects of potential importance are analyzed in detail.

General Description of New Haven Harbor

The New Haven Harbor estuary is located on the northern shore of Long Island Sound (Figure 1-1). The harbor, with its north-south axis, is a shallow embayment of approximately 8 square nautical miles of water surface within boundaries established by the Long Island Sound breakwaters and the mouths of the West, Mill and Quinnipiac Rivers. It is about 4 miles long and varies in width from about 4 miles at its mouth to about one-half mile just below the Tomlinson Bridge at its northern end. The harbor entrance is protected by three large stone breakwaters, the main channel entering through a gap between the easternmost and central breakwaters.

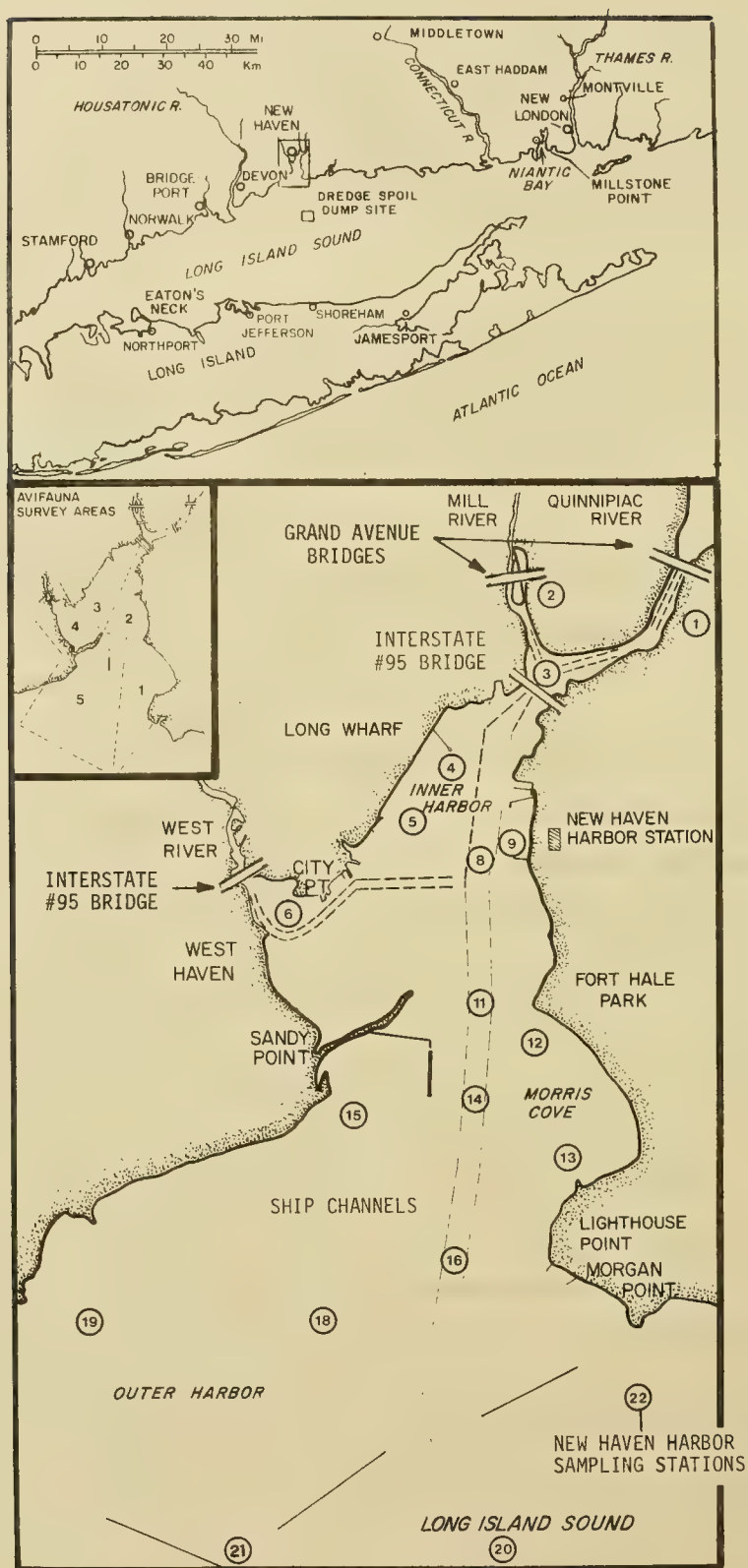


Figure 1-1. New Haven Harbor location map. New Haven Harbor Ecological Studies Summary Report, 1979.

The harbor channel, which varies in width from 400 ft to 800 ft and is 35-ft deep at mean low water, follows the eastern shore of the estuary where the naturally deepest water occurs. A large shoal area that is exposed or barely covered at low tide is located between Sandy Point and City Point on the west side of the harbor. The only shoal areas along the east side of the harbor are located southwest of the New Haven Harbor Station site, between the site and the harbor channel.

North of the Tomlinson Bridge, the harbor channel continues up the Quinnipiac River as far as Grand Avenue in a 200-ft wide by 16-ft deep section and up the Mill River in a channel that is 200-ft wide and 12-ft deep to the confluence of the East and West forks of the Mill River. Opposite the Harbor Station site, a 100-ft wide by 12-ft deep navigation channel diverges from the main harbor channel and proceeds up the West River to the Kimberly Avenue Bridge and thence 600 ft upstream in a section which is 75-ft wide by 9-ft deep.

Freshwater is fed into the harbor by the Quinnipiac, Mill and West Rivers which drain 164, 40 and 37 square miles, respectively. The mean annual runoff entering the estuary from these rivers is about 435 cfs, and the minimum annual runoff about 215 cfs.

Two tide gauges were maintained in New Haven Harbor by The National Oceanic Survey (National Oceanographic and Atmospheric Administration): one at Southwest Ledge Light, which is located at the eastern edge of the harbor entrance channel, and one within the harbor at Long Wharf. The mean tidal range is 6.2 ft at the harbor entrance and 6.3 ft within the harbor. The minimum tidal range is about 4.9 ft.

The tidal prism (water entering and leaving the harbor measured from mean low water to mean high water) is about 1.9×10^9 cu ft. The volume of the harbor is about 4.4×10^9 cu ft at mean sea level. Consequently, the volume of water entering the harbor over the approximate six-hour period from mean low water to mean high water or the volume leaving over the six-hour period from mean high water to mean low water is equivalent to 43 percent of the harbor volume at mean sea

level (EBASCO, 1971a). Averaged over the tidal cycle, the water entering and leaving the harbor flows at a rate of about 88,000 cfs; this is 140 times the 625 cfs Harbor Station cooling-water flow.

Two tidal current gauges were also maintained in the harbor by The National Oceanic Survey: one in the harbor entrance channel and the other at the Tomlinson Bridge. In the estuary channel inside the breakwaters the average current is approximately 0.4 knot or 0.68 fps.

The bedrock underlying the harbor area is probably a sedimentary deposit of Triassic age and consists solely of Arkosic sandstones. No shale or conglomerate has been observed in cores sampled in New Haven Harbor. New Haven Harbor is now a tidal estuary in which recent silts and sands are being deposited. Modified glacial soils deposited by running and quiet waters fill in the depressed regions resulting from glaciation; some soft organic silt containing fragments of shells occur above the glacial deposits.

Meteorology

Connecticut lies in a transition zone of westerly air currents that encompass the southward movement of dry polar air masses and the northern movement of moist tropical air masses. It is within this transition zone that storm centers form and move.

Superimposed on these large-scale effects are those created by New Haven's proximity to Long Island Sound. During the warmer months when air temperatures exceed those of the water, a sea breeze is likely to occur which tends to reinforce normal wind flow from the south or southwest during this season of the year. Such sea breezes occur only when the pressure gradient is weak along Long Island Sound. This marine environment moderates the climate of New Haven by producing cooler summers and warmer winters in comparison with those in inland areas. In addition, the low-level air mass wind speeds are increased by the sea breeze in spring and summer.

Wind-speed and direction instrumentation were in operation at Tweed New Haven Airport through 1969, although data were not recorded for full 24-hour periods. Continuous wind speed and direction readings are also obtained by The United Illuminating Company at the English Station, but the exposure of the instrument is poor for west to north-west winds. Comparison of concurrent New Haven data from the meteorological tower at New Haven Harbor Station and Bridgeport data indicated good agreement, and therefore, 10 years of continuous wind speed and direction data from Bridgeport were used to describe patterns of wind speed and direction after the meteorological station closed at Tweed New Haven Airport. Winter wind patterns showed strong flow from the northwest, characteristic of a post-frontal situation. The summer pattern showed the characteristic southwesterly flow that may be reinforced by the sea breeze.

Patterns of precipitation and temperature are presented in detail in Section 3.0; in general south-central Connecticut annually experiences about 45 inches of precipitation and has an annual mean temperature of approximately 50°F.

Extremes of meteorological conditions in the harbor area, such as extended drought or heavy precipitation, storm winds (hurricanes) or extremes of temperature are reflected in the harbor waters as salinity, wave, turbidity, and temperature effects. These effects were considered as they directly alter the harbor's hydrography and secondarily as they may have affected the biota. Specific occurrences are considered within individual discussion sections.

Harbor Usage

New Haven Harbor is visibly modified by its roles in commerce. The harbor waters serve as a reservoir for cooling water for several industrial and power-generating facilities, and a disposal ground for municipal and industrial wastes. Because the harbor serves as a major port (USACE, 1973a), it is subject to chronic, low level and occasional major oil spills, as well as impacts associated with maintenance dredging.

The waters of inner New Haven Harbor are classified as unacceptable by Connecticut Water Quality Standards with projected improvement by 1983 (Connecticut DEP, 1978). Discharges into the harbor include primary treated sewage from the East Street and Boulevard Treatment Facilities, and industrial effluents (NAI, 1975).

New Haven Harbor Station

The New Haven Harbor Station site is located in New Haven, Connecticut, on the eastern shore of New Haven Harbor about 4 miles above the estuary mouth (Figure 1-1). The site is situated on partially filled ground and lies about 8.4 ft above mean sea level. It is bounded on the south by East Shore Park and the expanded sewage treatment plant, on the east by the East Shore Parkway and the East Shore Sewage Treatment Plant; on the north by an oil tank farm and oil tanker unloading facilities; and on the west by New Haven Harbor. Approximately 1000 ft of shallow water separates the site from the New Haven Harbor channel. The channel is 800-ft wide and 35-ft deep at mean low water at this point.

The station is an oil-fired unit which commenced commercial operation on August 29, 1975. It is a nominal 400 Mw unit, and is capable of producing a maximum gross output of 460 Mw with a net station output of approximately 445 Mw. Actual operating data as daily average kilowatts per hour are presented in Figure 1-2.

A plot plan of the plant is shown in Figure 1-3. About 60 acres of land are enclosed between the existing riprap shoreline and the plant property lines to the east. The boiler, turbine generator, control room and administration building are in the southwest corner of the property while the fuel oil storage tanks are on the southeast corner. The circulating water intake channel extends from the center of the property at the existing riprap shoreline to the eastern edge of the navigation channel, and the subaqueous discharge pipeline is located just south of the existing oil unloading dock and extends 700 ft offshore from the riprap shoreline, terminating 300 ft east of the channel.

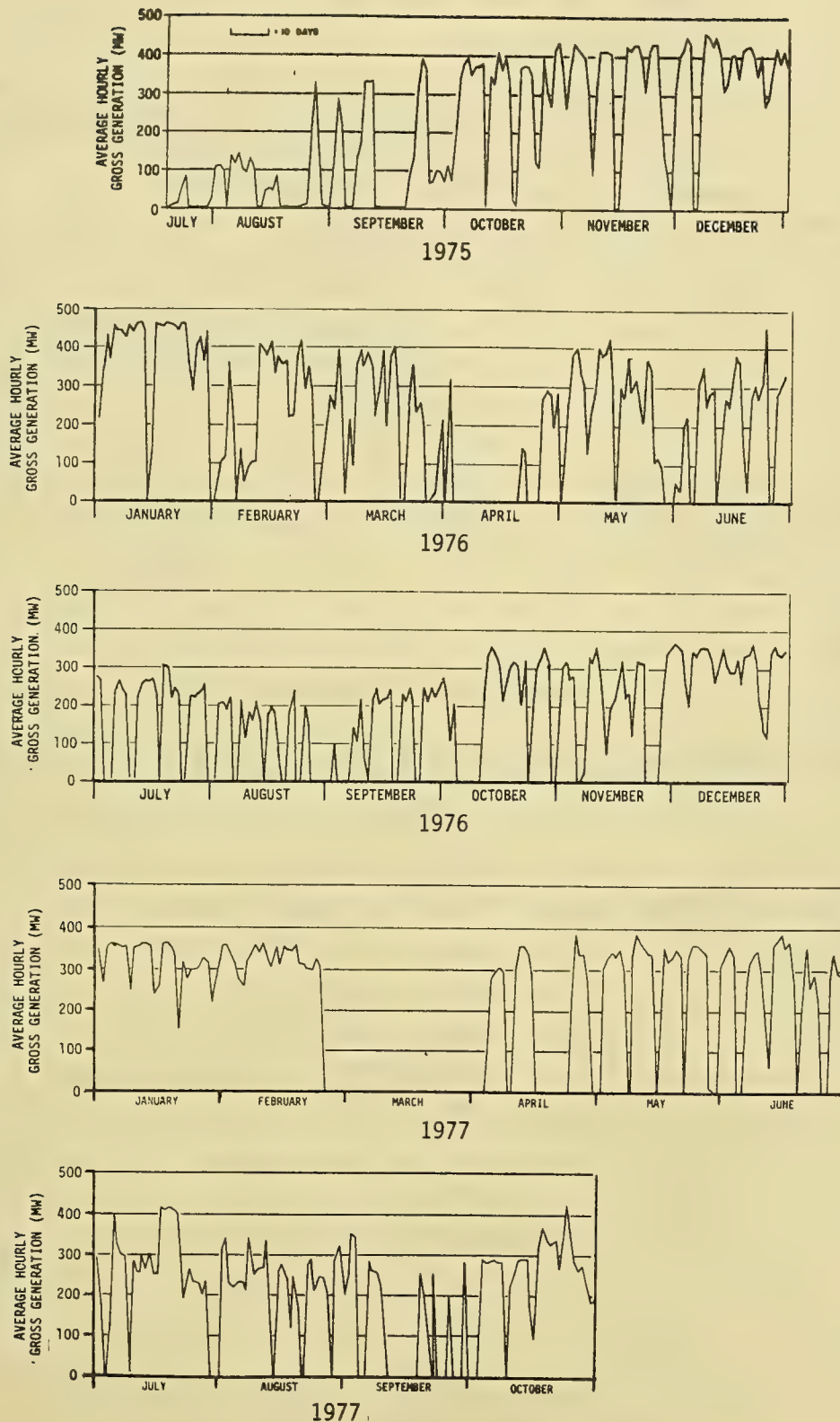


Figure 1-2. Average hourly gross electrical generation (in MW) plotted by day for New Haven Harbor Station, 1975 through 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

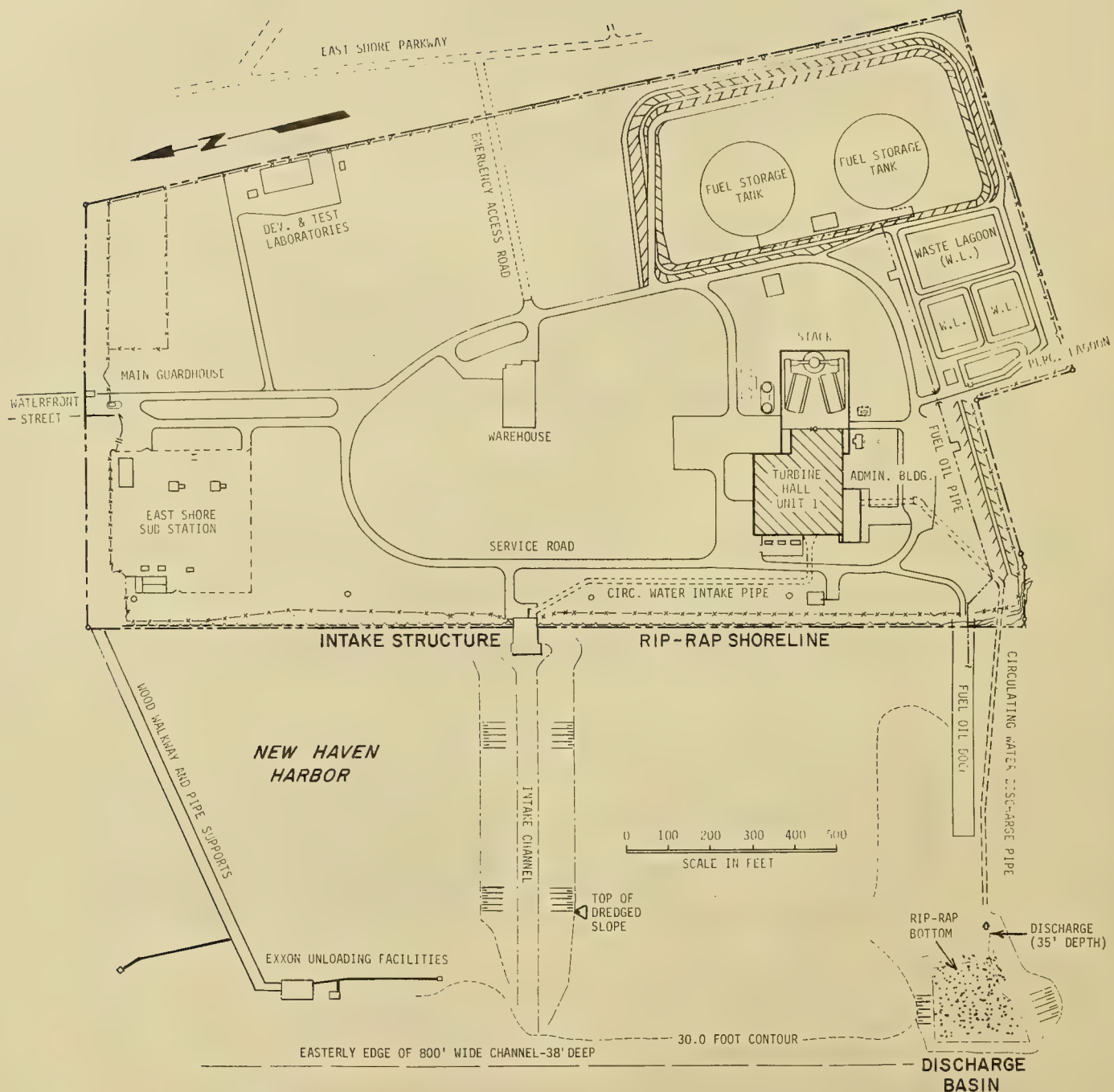


Figure 1-3. Plot plan of New Haven Harbor Station generating plant. New Haven Harbor Ecological Studies Summary Report, 1979.

The Harbor Station burns #6 fuel oil. This oil's high viscosity would reduce seepage into the soil in the event of a spill. The unloading pier is equipped with an oil boom, and a comprehensive oil spill contingency plan has been prepared.

Cooling Water

When operated at 100 percent load (gross rating), 625 cubic feet per second (cfs) (17.7 m^3 per second) of cooling water is pumped from the harbor through the plant to remove some 2100×10^6 BTU/hr (529 Kcal/hr) of waste heat from the condenser. In the process of removing this waste heat the temperature of the cooling water is raised approximately 15 F (8.3 C).

The cooling water for the unit's condenser is taken from and discharged into New Haven Harbor. The locations of the intake channel, intake structure, and discharge pipe are shown in Figure 1-3. The intake channel extends from the shoreline to the eastern edge of the harbor channel, a distance of about 900 ft. The cooling water is withdrawn from the intake channel via a reinforced concrete intake structure located at the existing riprap shoreline. The unidirectional flow of water into the intake results in accumulation of fish and debris on screens over the intake. The Federal Water Pollution Control Act Amendments of 1972 requires under Provision 316b that "the location, design, construction and capacity of cooling water intake structures reflect the best available technology for minimizing adverse environmental impact." To help prevent the entrapment and impingement of fish, the structure was designed so that the approach velocity in the structure prior to the traveling water screens is less than 1.0 ft per second (fps) (30.5 cm per second). In addition, the structure includes a "fish lip" or vertical wall 6 ft high in front of all openings to the coarse bar racks. This fish lip was designed to minimize entrapment and impingement of demersal fish. Details of the intake structure design are presented in Figure 1-4.

From the intake structure the cooling water is pumped through the condenser, heated 15 F and then discharged to New Haven Harbor through a 9-ft diameter subaqueous pipeline, terminating at a point approximately 700 ft offshore (Figure 1-3). The cooling water is discharged at a depth approximately 35 ft below mean low water level. Design velocity in the pipeline and at the point of discharge is about 10 fps (305 cm per second). The purpose of discharging the cooling water subaqueously is to promote rapid mixing with harbor water, and this results in a minimized temperature increase at the surface.

Drainage and Sanitary Wastes

The surface-water drainage system for the property empties into New Haven Harbor. Rainwater runoff accompanied by soil, pebbles, some dust and possibly leaves (natural runoff matter) is conveyed to the harbor through this system. The roof drains and surface drains are directed to the surface water drainage system.

Chemical wastes including boiler blowdown from the plant are collected, treated and released to a percolating lagoon where the water ultimately enters the groundwater table; unconcentrated solids are retained in the collection lagoons for disposal.

No biocides are used to control fouling organisms in the circulating water system; mechanical cleaning is used when necessary.

Trash and sanitary sewage disposals are routed to the New Haven city facilities. Trash collected from the traveling water screens and trash racks at the circulating water intake is transported in containers to the city dump. Sewage is treated at the East Shore Sewage Treatment Plant of the City of New Haven.

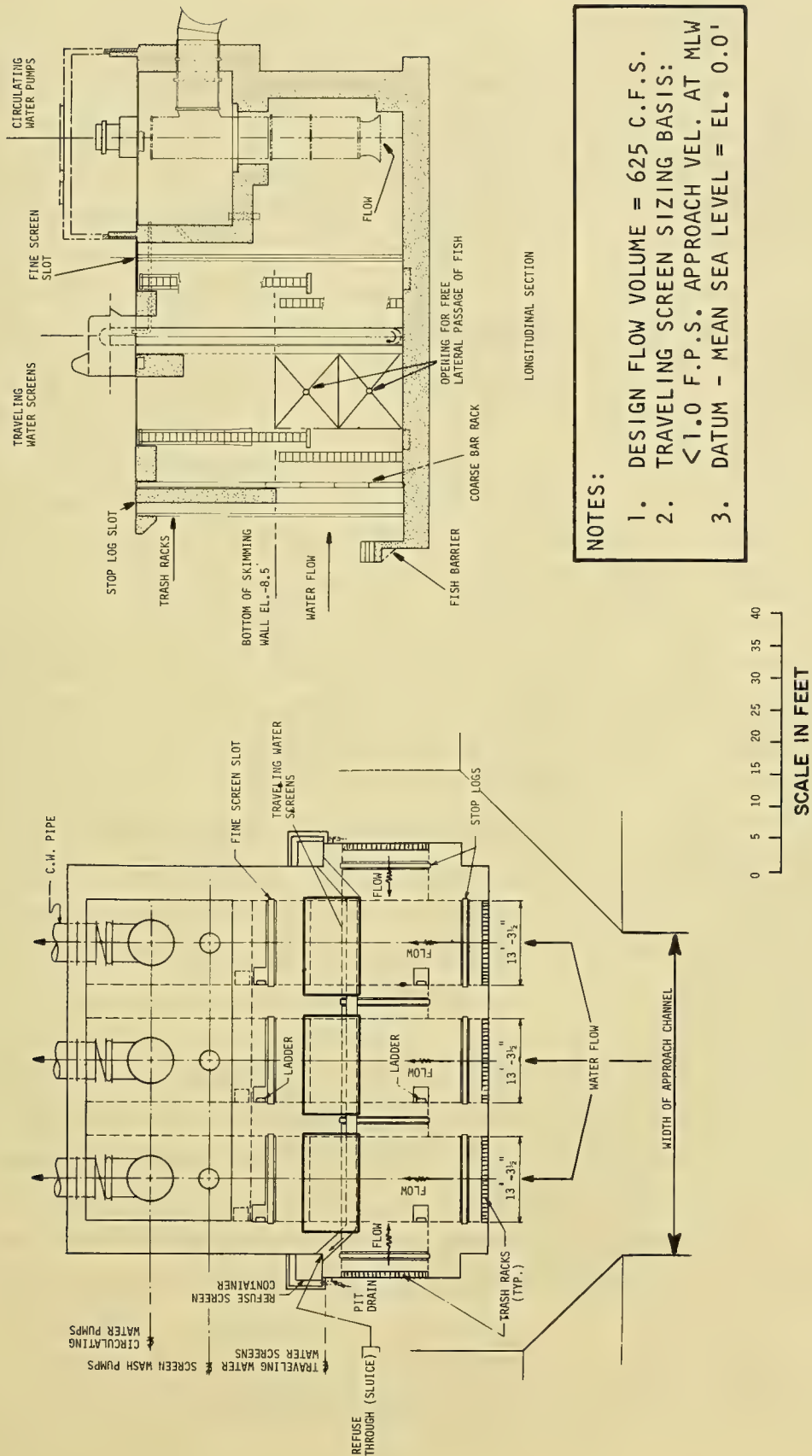


Figure 1-4. Plan of New Haven Harbor Station circulating water intake structure.
New Haven Harbor Ecological Studies Summary Report, 1979.

Siting and Related Studies

Earliest serious consideration of the New Haven Harbor environs as a site for a potential electric generating station was begun by Northeast Utilities Company in the mid-1960's; and evaluation of possible sites adjacent to the harbor from an environmental standpoint was made in 1967 (TRC, 1967). The United Illuminating Company pursued this possibility further, and in 1970, environmental and design engineering studies were begun for a 400-MW, oil-fired generating station proposed for the present site; this area, then owned by UI, was formerly the Connecticut Coke Company.

Environmental studies commenced with studies of the harbor's macroalgae communities (Prince and Melville, 1970) and plankton surveys (Raytheon, 1970). These early studies led to a multidisciplinary baseline study executed from June 1970 through April 1971 (Raytheon, 1971a, 1971b, 1971c). Data from these studies were used for the preparation of an Environmental Report (EBASCO, 1971b) and were incorporated into the Draft Environmental Statement (Army Corps of Engineers, 1971) which served as a basis for subsequent environmental monitoring studies. The DES was duly circulated to interested citizens, citizens' groups and agencies for comments, which were received and responded to, and the U.S. Army Corps of Engineers released a Final Environmental Statement in compliance with the National Environmental Policy Act of 1972 on June 15, 1973 (Army Corps of Engineers, 1973b).

Studies to determine the hydrodynamic characteristics of the harbor and to model the proposed discharge of condenser cooling water were conducted by Ebasco Services in 1970 and 1971. Results of these studies and model studies (University of Florida, 1972) confirmed the feasibility of utilizing once-through cooling in the proposed generating station, and provided design specifications for the discharge structure.

Numerous studies were conducted for UI on anticipated and realized impacts of construction of New Haven Harbor Station facilities.

Anticipation of dredging requirements for construction of the intake and discharge structures resulted in the following studies: analyses of sediments to be dredged (NAI, 1971, 1972); alternatives for dredge spoil disposal (NAI, 1972; Gordon, Rhoads and Turekian, 1972); impacts of dredging (Gordon, 1973a); and impacts of dredge spoil disposal in Long Island Sound (Gordon, 1973b; Pratt and O'Connor, 1973; Rhoads, 1972a, 1973b).

During New Haven Harbor Station construction, observed seagull mortality at the construction site led to a brief pathological study which concluded that the deaths were due to Aspergillosis, a contagious fungal disease of birds. It was concluded that this disease was in no way related to construction activities (NAI, 1974a).

After New Haven Harbor Station construction was completed, further dredging-related studies were conducted to assess the impacts of construction of transmission lines from New Haven Harbor Station to English Station. Assessed impacts included dredging, benthic habitat removal, and land disposal in East Shore Park (NAI, 1975a, 1975b).

Five studies were also conducted after operations commenced in 1975 with objectives of describing and evaluating actual or potential plant impacts. A study of current velocities around the intake structure (with various combinations of the three cooling water pumps in operation) was conducted in order to evaluate whether operation met design specifications (NAI, 1973). A three-dimensional thermal survey and aerial infrared imagery described the thermal characteristics of the harbor during New Haven Harbor Station operations and delineated the discharge plume in a limited fashion (NAI, 1976a). Later, NAI (1977a) completed a series of thermal and dye studies to more precisely describe the plume. An assessment of the thermal toxicity of the discharge to representative New Haven species was presented in a literature review (NAI, 1976b). When biofouling of the condenser tubes became an operational problem in 1976, NAI (1976c) studied the identity and composition of the fouling bacteria and assessed the viability of treatment with biocides to solve the problem.

Monitoring Studies Program

Comprehensive environmental monitoring studies, the main subject of this report, were commenced in May 1970 and continued through October 1977 in New Haven Harbor. The monitoring program was designed to evaluate the effect of United Illuminating's New Haven Harbor Station on the water quality and biota of the Harbor.

In broad terms, the objective of the monitoring program was to provide a basis for evaluating whether or not the plant was adversely impacting the New Haven Harbor environment. Certain provisions of the NPDES "Permit to Discharge" issued in October 1973 specifically addressed environmental matters that were directly relevant to the monitoring program design:

1. No effluent may be acutely toxic to any indigenous species in New Haven Harbor (Special Conditions [General] [4]);
2. The discharge shall not interfere with the spawning of fish or invertebrates (Special Conditions [Specific] (1) g);
3. The discharge shall not alter the balanced indigenous population of New Haven Harbor or its tributary waters (Special Conditions [Specific] (1) h);
4. The thermal plume shall not block zones of fish passage (Special Conditions [Specific] (1) i); and,
5. The thermal plume shall have minimal contact with the surrounding shoreline (Special Conditions [Specific] (1) j).

These conditions have all been taken into account through direct studies of the thermal plume, through the detailed monitoring program, or through theoretical considerations.

The primary direct discharge from the plant into harbor waters is the cooling-system water to which plant operation adds its waste heat; no other toxic element is contributed by the station. The waste heat is not anticipated to impact harbor biota directly, based on a consideration of known temperature tolerances for 14 selected representative species of fishes and invertebrates. This conclusion is qualified by maintenance of water temperatures within the imposed discharge temperature limitations of ΔT 15°F and a 90°F maximum (NAI, 1976).

The permit conditions related to blockage of "zones of passage" and "contact with the surrounding shoreline" are satisfied by the thermal plume description studies including the 1976 infrared overflight and 1977 dye and thermal surveys.

The answers to the question as to whether or not there has been interference with spawning and alteration of the "balanced indigenous population of New Haven Harbor or its tributary waters" has been a basic consideration of the ecological monitoring program. Guidance with regard to these concerns was provided by the US EPA (1977b). Specifically, EPA (1977b) stated:

Any significant change in standing crop may indicate an adverse impact resulting from the heated discharge, and any appreciable alteration in the composition and relative abundance ... constitutes an imbalance in the community and indicates possible adverse impact.

Though the New Haven Harbor Station Ecological Monitoring Studies program was designed prior to this specific EPA statement, the program design quite clearly reflects these considerations. The program objectives were to establish baselines of patterns in ecological parameters so that possible deviations could be identified after the plant commenced operation. Impacts, adverse, non-important or beneficial, were to be sought in changes of composition, relative abundances and spatial and temporal distributions.

The monitoring program for operational impacts in New Haven Harbor is based on a series of facts and assumptions that are important to understanding the approach utilized for the analysis of impacts in this report:

1. The harbor has an apparent (though untested) high exchange rate with Long Island Sound. This is deduced from the large tidal prism (43% of harbor volume at MSL), and the general LIS net flow pattern past the harbor mouth (EBASCO, 1971).
2. The cooling water flow of New Haven Harbor Station is only 0.7% of the average tidal flow rate.

These two facts are the basis for the assumption that even under the worst conditions of total mortality of entrained organisms, exchange with Long Island Sound waters and associated plankton populations would override any potential plant-operationally induced reduction in population abundances.

Study of plankton populations was geared toward detection of any shifts in dominance or abundance levels, particularly by consideration of spatial differences. Sampling was performed throughout the harbor. The generating station impact on plankton populations was considered to be within acceptable limits provided that species composition, abundance levels and the relationship of species distribution between stations remained similar throughout preoperational and operational periods. Any observed qualitative changes would need to be examined in detail, their potential ecological importance considered, as well as their spatial extent and longevity.

"Analysis of Impacts" in each section of this report provides a comprehensive description of mechanisms of potential impact, considers the potential of available data to evaluate the impacts, and proceeds to examine the data for plant effects. Where possible changes in standing

crop, composition or relative abundance (EPA, 1977b), or in harbor utilization patterns are observed, extent of changes, limitations on the analytical methods and implications of the impacts are discussed in detail.

The discharge from the plant cooling system was designed for rapid mixing of the heated effluent with harbor waters. Maximum observable temperature increase predicted by the University of Florida physical model (University of Florida, 1972) when the buoyant plume intersected the surface was small 2.2°C (4°F). Further, since the plume discharges at the edge of the shipping channel, an area characterized by strong surface currents, little buildup of heated waters was anticipated; thus, the plume would be difficult for any fish to "follow". This discharge was also expected to minimize the likelihood of any problem with cold shock of fish or epibenthic invertebrates whose presence depended on the elevated temperature of the thermal plume. Plume entrainment of planktonic organisms was also expected to have negligible impact because there would be a minimal temperature elevation of short duration. Similarly, contact of the thermal plume with any shoreline or benthic habitat was expected to be minimal if it occurred at all. If the plume should impinge upon the shoreline, temperature elevations were expected to be low and duration brief.

Sample stations utilized for the studies are shown in Figure 1-1. Sampling frequencies, stations, and techniques for both the biological and water quality parameters are summarized in Table 1-1. Physical-chemical water-quality parameters were monitored on a monthly basis at 17 stations. Those parameters measured were depth-related temperature, salinity, dissolved oxygen, hydrogen ion concentration (pH), and water transparency. Eight biological programs were conducted in conjunction with the water-quality sampling. Sampling frequency, number of stations, and station locations varied with each parameter for the biological program. Monthly year-round sampling was established to monitor chlorophyll *a*, phytoplankton, zooplankton, ichthyoplankton, exposure panel biota, oyster growth, avian composition, and finfish

TABLE 1-1. SUMMARY OF SAMPLING REGIME FOR NEW HAVEN HARBOR STATION ECOLOGICAL STUDIES AS IT EXISTED IN OCTOBER, 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

PROGRAM	SAMPLING TECHNIQUE	MONTHS												STATIONS	REPLICATES	DEPTHS	TIDES
		J	A	S	O	N	D	J	F	M	A	M	J				
Physical/ Chemical	As required	x	x	x	x	x	x	x	x	x	x	x	x	1,2,3,4,5,6,8, 9,11,12,13,15, 16,18,19,20,22	None	Surf. to bottom 1 meter increments	Ebb, Flood
Chlorophyll a	1 liter bottle	x	x	x	x	x	x	x	x	x	x	x	x	2,3,6,8,11,18,20	None	Surface	Ebb, Flood
Phytoplankton	250 ml bottle	x	x	x	x	x	x	x	x	x	x	x	x	2,3,6,8,11,18,20	None	Surface	Ebb, Flood
Zooplankton	1/2 meter #10 mesh net	x	x	x	x	x	x	x	x	x	x	x	x	3,6,8,11,18,20	None	Near surface near bottom	Ebb, Flood
Ichthyoplankton	1 meter .505mm mesh net	x	x	x	x	x	x	x	x	x	x	x	x	3,6,8,11,18,20	None	Oblique surface-bottom	Ebb, Flood
Gill Nets	150' variable mesh	x	x	x	x	x	x	x	x	x	x	x	x	8a,8,13,19	None	Near Bottom	
Shore-Zone Seining	100' bag seine	x	x	x	x	x					x	x	x	Sandy Point, Long Wharf, Harbor Sta- tion, Morris Cove	None		
Otter Trawls	25' Otter	x	x	x	x	x	x	x	x	x	x	x	x	5,8,11,13,19,22	Duplicate		
Exposure Panels	Wood/ asbestos Panels	x	x	x	x	x	x	x	x	x	x	x	x	Harbor Station, Long Wharf, Fort Hale	None	Near Surface	
Bird Observations	Visual Obser- vations	x	x	x	x	x	x	x	x	x	x	x	x	Areas 1,2,3,4,5	None		
Subtidal Benthos	Ponar Grab	x	x					x					x	3,5,6,8,11,13	Five		
Intertidal Fauna and Flora	1/16m ² cofferdam			x									x	Long Wharf, Harbor Station Pier areas Sandy Point	Duplicate	mid tide, low tide lines	
Oyster Growth	Oyster Cages	x	x	x	x	x	x	x	x	x	x	x	x	Fort Hale, Harbor Station Pier areas	None		
Oyster Condition Index	Oyster Cages			x									x	Harbor Station Pier, Fort Hale	As indi- cated		

populations (gill net, trawl). Shore-zone fish seining was conducted monthly with exception of the winter months. Sample scheduling for the remaining programs, intertidal fauna and flora, benthic infauna, and determination of the oyster condition index was designed to assess seasonal changes in the biota.

As stated above, the objectives of this report are to describe the ecology of New Haven Harbor, and to identify and evaluate possible impacts of the plant operations on the harbor ecosystem. The intention is to produce a thorough and synthesized "description" which could serve as a foundation for consideration of environmental impacts and, secondly, to provide a useful basis for comparison by other researchers with other estuaries and harbors or with New Haven Harbor in future studies. Prior to this report there was no comprehensive body of ecological information on New Haven Harbor. Short-term studies that generally rely on monthly or seasonal sampling efforts have a probability of missing some major short-lived occurrences in either physical or biological parameters. On the other hand, the New Haven Harbor Ecological studies, which relied on monthly data-acquisition over all seasons for seven consecutive years provides an excellent base for characterizing environmental conditions in New Haven Harbor.

LITERATURE CITED -- INTRODUCTION

- Connecticut Department of Environmental Protection. 1978. Connecticut water quality standards and classifications. 89 pp.
- EBASCO. 1971a. Coke Works Generating Plant effect of heated cooling water discharge on the temperature distribution of New Haven Harbor. Prepared for United Illuminating Co., New Haven, Connecticut. 19 pp.
- EBASCO. 1971b. Environmental report: Coke Works Site, June 1971. Prepared for United Illuminating Company, New Haven, Connecticut. 10 sections.
- Environmental Protection Agency. 1977. Federal Register.
- Gordon, R. B. 1973. Turbidity due to dredge operations at the Coke Works Site, New Haven Harbor, Connecticut: Initial Study Results. Prepared for United Illuminating Company, New Haven, Connecticut.
- Gordon, R. B., D. Rhoads and K. K. Turekian. 1972. The environmental consequences of dredge spoil disposal in central Long Island Sound: I. The New Haven Spoil Ground and New Haven Harbor. Report to the New England Division, U.S. Army Corps of Engineers, October 1972.
- Merriman, D. and L. M. Thorpe (eds.). 1976. The Connecticut River Ecological Study. The impact of a nuclear power plant. Am. Fish. Soc., Monogr. No. 1. 252 pp.
- Normandeau Associates, Inc. 1971. Ecological considerations of the Coke Works Site, New Haven Harbor, Connecticut. Prepared for the United Illuminating Company, New Haven, Connecticut. 64 pp.
- _____. 1972. Addendum 12 of environmental report: Coke Works Site, June 1971. Marine Sediments, New Haven Harbor, Connecticut. Results of analyses and proposals for dredge spoil disposal. Prepared for United Illuminating Company, New Haven, Connecticut. 134 pp.
- _____. 1973a. New Haven Ecological Studies, New Haven, Connecticut. Annual Report, 1971-1972 for the United Illuminating Company, New Haven, Connecticut. 208 pp.
- _____. 1974. Supplemental research on the effects of thermal discharge from the English Generating Station on the ecology of Grand Avenue Reach, New Haven Harbor, Connecticut. Prepared for the United Illuminating Company, New Haven, Connecticut. 120 pp.
- _____. 1975a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1974 for the United Illuminating Company, New Haven, Connecticut. 223 pp.

- _____. 1975b. Ecological studies conducted at selected sites in New Haven Harbor, Connecticut. Prepared for the City of New Haven, Connecticut. 115 pp.
- _____. 1975c. Potential effects of the October 1974 oil spill on New Haven Harbor Ecology. Prepared for the United Illuminating Company, New Haven, Connecticut. 35 pp.
- _____. 1976a. New Haven Harbor Thermal Regime during operation of the New Haven Harbor Station, September 1975. Prepared for the United Illuminating Company, New Haven, Connecticut. 31 pp.
- _____. 1976b. New Haven Harbor Station Ecological Monitoring Studies, 1976: Acute Toxicity Studies. Prepared for the United Illuminating Company, New Haven, Connecticut. 64 pp.
- _____. 1976c. New Haven Harbor Station Condenser Tube Fouling Study (draft). Prepared for the United Illuminating Company, New Haven, Connecticut. 12 pp.
- _____. 1977. Thermal surveys, New Haven Harbor, summer and fall, 1976. Prepared for the United Illuminating Company, New Haven, Connecticut. 70 pp.
- Pratt, S. D. and T. P. O'Conner. 1973. Burial of dredge spoil in Long Island Sound. Prepared for Normandeau Associates, Inc. and submitted to United Illuminating Company, New Haven, Connecticut.
- Prince, J. S. and L. A. Melville. 1970. New Haven Report, Algal. June and August 1970. unpublished. 5 pp.
- Raytheon. 1970. New Haven Harbor Plankton Survey, April-May 1970. Prepared for United Illuminating Company, New Haven, Connecticut. 49 pp.
- _____. 1971a. New Haven Ecological Survey Data Report, June-December 1970. Prepared for United Illuminating Company, New Haven, Connecticut. 179 pp.
- _____. 1971b. New Haven Harbor Ecological Survey, Data Report, December 1970-April 1971. Prepared for United Illuminating Company, New Haven, Connecticut. 11 sections.
- Rhoads, D. 1972a. The environmental consequences of dredge spoil disposal in central Long Island Sound: I. Benthic biology of the New Haven dump site. unpublished report to U.S. Army Corps of Engineers and the United Illuminating Company. 40 pp.
- _____. 1973b. The environmental consequences of dredge spoil disposal in central Long Island Sound. III: Benthic biology of the south central site, 1972. Prepared for United Illuminating Company.
- TRC Service Corporation. 1967. Preliminary site evaluation, Fort Hale, New Haven, Connecticut. Prepared for the Northeast Utilities Service Company, Berlin, Connecticut. 75 pp.

United States Army Corps of Engineers. 1971. Draft environmental statement: New Haven Harbor, Connecticut

_____. 1973a. Final environmental statement: New Haven Harbor, Connecticut Maintenance Dredging. 171 pp and appendices.

_____. 1973b. Environmental statement, Coke Works electric generating plant, New Haven Harbor, Connecticut.

University of Florida. 1972. Buoyant jet discharge model study for Coke Works power plant, New Haven Harbor, Connecticut. DCOE, FEIES, University of Florida.

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

2.0 LITERATURE OVERVIEW

by C. Drew Harvell and Kenneth A. Simon
Normandeau Associates, Inc.
Bedford, N. H.

TABLE OF CONTENTS

	PAGE
<i>WATER QUALITY AND HYDROGRAPHY.</i>	2-2
<i>PLANKTON</i>	2-4
<i>FINFISH.</i>	2-5
<i>AVIFAUNA</i>	2-7
<i>BENTHOS.</i>	2-7
<i>BIBLIOGRAPHY</i>	2-11

2.0 LITERATURE OVERVIEW

by C. Drew Harvell and Kenneth A. Simon
Normandeau Associates, Inc.
Bedford, N. H.

This literature overview is intended to provide an introduction to the general and comparative literature available for New Haven Harbor and greater Long Island Sound. The review is not intended to be comprehensive; that function is left to the individual report sections. This material includes comparative information on historical and existing biotic and abiotic parameters in New Haven Harbor and greater Long Island Sound and is meant to aid in the evaluation of potential plant impact. The review is divided into five primary sections dealing with water quality and hydrography, plankton, finfish, avifauna and benthos. Sources for much of this information include NAI data files, utility reports for generating stations, and records maintained by private and governmental agencies.

A substantial quantity of information is available concerning the general ecology of Long Island Sound and its shores as well as the ecology and habits of specific organisms common to New Haven Harbor and the Sound. The particular scope of this review encompasses the general ecology of central and western Long Island Sound and New Haven Harbor (Figure 1-1). The emphasis rests on providing information from New Haven Harbor, comparable harbors on the north side of the Sound, other power plants, and Long Island Sound in general. Most studies reported herein were conducted during the past ten years, corresponding to the period of intensive baseline, preoperational and operational monitoring studies in New Haven. Studies conducted prior to this period are included when they provide direct historical comparison or were the only sources available. Further information on selected individual citations is presented as annotations in the accompanying bibliography.

WATER QUALITY AND HYDROGRAPHY

General water quality information, including dissolved oxygen, salinity, pH, temperature and public-health related data (primarily total fecal coliform bacteria counts) is available from a number of studies. Data on nutrients and trace contaminants are more limited. Information on hydrographic characteristics is available from studies conducted both in New Haven Harbor and Long Island Sound.

Data for New Haven Harbor are available from Duxbury (1964), who provided seasonal information on nutrient concentrations and distributions and current regimes in the harbor. Beginning in 1968 the United States Geologic Survey Water Resources Division (U.S.G.S., 1968-1977) conducted a general water resources survey, providing data on a wide spectrum of water quality and chemical parameters involving several samplings per year from stations in the Quinnipiac and Mill Rivers and New Haven Harbor. A later study (1970, unpublished) conducted by the Federal Water Quality Administration provided measurements of dissolved oxygen and pH from inner and outer harbor locations. NAI (1971a, 1972, 1973, 1974a, 1974b, 1975a, 1976a, 1977a, 1978) has provided a substantial water quality data base (temperature, dissolved oxygen, pH, salinity and turbidity) for the inner and outer harbor regions. Additional water temperature data are available from aerial infrared surveys (Goodkind & O'Day and Fay, Spofford, and Thorndike, 1970; NAI, 1971, 1977b) for determining effluent plume configurations and from thermal plume baseline studies for the English Station (NAI, 1971) and New Haven Harbor Station (EBASCO, 1971b; NAI, 1976b). The Goodkind harbor model was directed primarily toward modeling of dissolved oxygen and biological oxygen demands of various sewage treatment/outfall location schemes.

Duxbury's study on water circulation in New Haven Harbor has been the only major effort to utilize a full field measurement program. Duxbury's general circulation patterns and current velocities have served as basic elements of nearly all subsequent hydrodynamic work in New Haven Harbor. These data were used in the circulation model of

Quirk, Lawler and Matusky (1969) and water quality model of Goodkind et al. (1970). Water quality models have been prepared for the harbor and Quinnipiac River as part of sewage treatment facility design and water management programs (Quirk, Lawler and Matusky, 1969; Goodkind et al., 1970; and Connecticut Department of Environmental Protection, 1977). More recent work conducted for sewage outfall location studies (NAI, 1975b) provided supplemental data on surface and near surface currents. At the present time, a new dynamic model of the harbor is being prepared based on new current and tide data (NAI, 1979, unpublished).

Outside of New Haven Harbor, water quality data are more abundant for the central and western sections of Long Island Sound. The State University of New York (SUNY) Marine Science Research Center published data on seasonal fluctuations in dissolved oxygen and temperature (Hardy and Weyl, 1970, 1971) and nutrients (Hardy, 1972 and 1972b). The National Marine Fisheries Service (NMFS) from Sandy Hook, New Jersey, initiated an extensive environmental baseline study for the Sound in 1972; data have been collected since then, though only small amounts have been published. Information on chemistry, nutrients, and temperature is available in Reid, Frame, and Drexler (1976), and further studies on nutrients and their distribution include a Sound-wide study by Bowman (1977). Monitoring programs at Stamford (NAI, 1974c), Bridgeport (NAI, 1973), Niantic Bay (Battelle, 1977, 1978), Shoreham, (NYOSL, 1974), Norwalk Harbor, Housatonic River at Devon, Connecticut River at Middletown and Thames Estuary at Montville (Lawler, Matusky and Skelly Engineers, 1975a, 1975b, 1975c and 1976) provide information on seasonal variation and water quality gradients from coastal areas throughout the Sound. Data are also available from a predictive model of water temperature gradients in the Sound and the impact of power plant discharges (Stone and Webster, 1972). In addition, temperature loss from surface waters of a thermal plume to the overlying air mass during calm and windy conditions was studied by Williams (1971) at Northport, New York.

Extensive studies of water mass movement and general water circulation in the Sound have been undertaken during the past 20 years. The majority of the early work was carried out from the Bingham Oceanographic Laboratory, Yale University; thus, Riley (1956, 1959) and Riley and Conover (1956) provided data concerning general circulation and hydrographic parameters for the Central Sound. More recent studies of circulation in the western and to a lesser degree central Sound have been conducted from SUNY by Hardy and Weyl (1970), Hardy (1972), and Jay and Bowman (1975).

PLANKTON

Investigations of the plankton community generally include zoo-, phyto-, and ichthyoplankton populations. These populations form the base of the food chain and, because of their importance, have been widely studied in greater Long Island Sound. Data from New Haven Harbor are available from studies conducted by NAI for United Illuminating Co. (Raytheon, 1970a, 1971, and NAI, 1973, 1974a, 1974b, 1975a, 1976a, 1977a, 1978a). This information provides baseline preoperational and operational data on zooplankton, phytoplankton and ichthyoplankton populations in the harbor, and is the basis for this summary report.

The earliest studies of greater Long Island Sound plankton were undertaken during the early to mid-1950's. During this period, programs conducted through the Bingham Oceanographic Laboratory included studies of zooplankton (Deevey, 1956), ichthyoplankton (Richards, 1959) and phytoplankton (Conover, 1956, and Riley and Conover, 1967). The greatest emphasis of these studies was placed on populations from the central region of the Sound. During the 1970's extensive work was done on inshore and near-shore plankton populations in the central region of the Sound as part of power-plant baseline and monitoring programs. Thus, at Bridgeport a small-scale zooplankton sampling program was conducted as part of an operational monitoring program during summer and fall of 1971 (NAI, 1973b). Substantial work has also been conducted for

the Long Island Lighting Company at Northport, Port Jefferson, Shoreham and Jamesport. Baseline and preoperational studies, conducted during 1973 and 1974, included work on zooplankton at Shoreham (NYOSL, 1974) and ichthyoplankton studies at Shoreham (NYOSL, 1974), Jamesport (Austin, 1974b) and at Northport (Williams, 1971; Austin, Dickerson and Hickey, 1974). Baseline and preoperational phytoplankton data are available from Jamesport (Nuzzi, 1975) and Shoreham (NYOSL, 1974), respectively. Later ichthyoplankton studies were conducted at Port Jefferson, Northport and Glenwood (EEH, 1977a, b, c). Data are also available for the tidal reaches of the Mill River (NAI, 1974e).

In the western region of the Sound the National Marine Fisheries Service (1971, unpublished) conducted a small sampling program. Further studies in the western Sound include inshore programs at Stamford for ichthyo-, zoo-, and phytoplankton diversity (NAI, 1974c), general plankton populations in western Sound waters (NYOSL, 1974), western Sound copepod populations (NYOSL, 1974), and vertical distribution of winter zooplankton populations (Caplan, 1976). The Corps of Engineers also conducted an extensive study of planktonic populations in the immediate vicinity of the mid-Sound Eatons Neck dredge spoil disposal site (Caplan, 1977; Nuzzi, 1977).

In the eastern Sound, preoperational and operational plankton studies investigating seasonal distributions of zooplankton and phytoplankton and diurnal studies on ichthyoplankton were conducted at Niantic Bay by Battelle (1977, 1978).

FINFISH

New Haven Harbor and Long Island Sound support an abundant and diverse ichthyofauna. Considerable information is available concerning habits, general distribution, and ecology of many of the species common to the Sound (Project Oceanology, 1977). However, relatively little information is available concerning seasonal abundances and degree of utilization of New Haven and other Long Island Sound estuaries.

The only previous survey of shore-zone fishes in New Haven Harbor is provided by Warfel and Merriman (1944), and that was confined to Morris Cove. No historical data are available on demersal and pelagic species in the harbor. Recent data (including abundances, distribution, and size) on these populations in the harbor were collected as part of baseline and monitoring programs for the Harbor (Raytheon, 1970, 1971; NAI, 1971a, 1973, 1974a, 1974b, 1974c, 1974e, 1975a, 1976a, 1977a, and 1978). A fisheries study was conducted for the City of New Haven in the harbor (NAI, 1975b).

Contemporaneous fisheries studies providing information on seasonal distributions and abundance were conducted at a number of sites in the Sound. Along the northern shore of the Sound, data are available from studies in Stamford and Bridgeport Harbors (NAI, 1974d and 1973b), Niantic Bay (Battelle, 1977) and New London (Department of the Navy, 1977). Hillman *et al.* (1977) described shore-zone fishes at Niantic Bay and their lack of response to a thermal discharge. Along the south shore of the Sound, comprehensive studies were conducted at Shoreham and Northport power plant sites (NYOSL, 1973 and 1974; Zawacki and Briggs, 1976; and Perlmutter, 1971). These programs are not comparable in terms of methods and equipment with those conducted on the north shore of the Sound, but they do illustrate general population trends in Long Island Sound.

A number of programs evaluating impingement at power plants provide some information on community composition and seasonal trends in abundance. Data are available from the Thames Estuary (Montville Station), Connecticut River (Middletown Station), Housatonic River (Devon Station) and Norwalk Harbor (NUSCO, unpublished); Bridgeport and New Haven Harbor (UI unpublished); Niantic Bay (Millstone Point) (Battelle, 1977, 1978); Northport, Port Jefferson, and Glenwood, Long Island (Equitable Environmental Health, 1977).

General life-history information from the Sound includes studies on striped bass (Austin and Custer, 1977; Clark, 1968; Schaeffer

1972), winter flounder (Jeffries and Johnson, 1974; McCracken, 1963; Pearcy, 1962), summer flounder (Powell and Schwartz, 1977), and studies on the general distribution of pelagic and demersal fishes in the Sound (Pearcy and Richards, 1962; Jensen, 1977; Alperin and Schaeffer, 1965; Richards, 1963).

AVIFAUNA

The most comprehensive source of data describing bird life in New Haven Harbor is that generated by the New Haven Harbor Station baseline and monitoring programs (Raytheon, 1971; NAI, 1971a, 1973, 1974a, 1974b, 1975a, 1976a, 1977a, and 1978a). These data provide information on seasonal variation in species composition, abundance, and distribution in the harbor. Additional sources of information include the U.S. Fish and Wildlife Service mid-winter waterfowl inventory (NAI, 1971), Christmas bird census and records of sightings of rare or unusual birds in the New Haven area (Conn. Audubon, 1977). Sources of information on bird populations in the remainder of the Sound include the Fish and Wildlife mid-winter survey and Audubon Christmas bird count. The R.I. Dept. of Natural Resources, and Conn., R.I. and N.Y. Audubon Societies provide useful information as well. In addition to these data, the New York Department of Environmental Conservation collects mid-winter bird counts along the north and south shores of Long Island (N.Y.D.E.C., 1977).

BENTHOS

Included in studies of the benthos are subtidal and intertidal infauna, epifauna and flora, as well as exposure panel communities.

In the central region, infaunal, epifaunal and floral surveys in New Haven were made in conjunction with United Illuminating's New Haven Harbor Station. Surveys covering subtidal and intertidal flora

and fauna were conducted by Raytheon (1971) and NAI (1973, 1974a, 1974b, 1975a, 1976a, 1977a, and 1978). During 1974, additional benthic and intertidal studies were conducted for the City of New Haven (NAI, 1975b). Cunningham (1972, unpublished) also conducted a year-long survey of the Long Wharf flats on the western side of New Haven Harbor.

An assessment of dredge spoil disposal activities was undertaken at the New Haven dumping grounds for the Corps of Engineers by Rhoads (1972, 1973a, 1973b, 1973c, 1973d, 1973e, 1974a, 1974b, 1974c, 1975; Rhoads, Allen and Goldhaber, 1975). During an investigation of the New Haven dumping grounds, Rhoads also conducted a survey of pre- and post-dredged benthic communities in the New Haven shipping channel (Rhoads, 1973a, 1973e, 1974b, 1974c) for the Corps of Engineers. Rhoads and Michael (1975, 1976, 1977, 1978) carried out seasonal investigations of subtidal communities in New Haven's inner harbor region and Morris Cove in conjunction with the United Illuminating program. Other studies conducted at or in the vicinity of the New Haven dump site included assessment of recolonization of dredge spoil and community structure (Franz, 1976; McCall, 1977; Fisher and McCall, 1973). Epi-faunal data are also available from impingement records maintained by the United Illuminating Company.

Benthic investigations in central Long Island Sound were first conducted by Sanders (1956) as part of the overall Bingham Oceanographic Laboratory survey on the oceanography of Long Island Sound. During the period between 1972 and 1975, the National Marine Fisheries Service conducted an environmental baseline study for the Sound. Benthic infauna were sampled at over 100 stations during the first year of the program, and sampling on a reduced scale continued through 1975. To date, benthic samples from the earlier years have been analyzed but no formal reports have been prepared. The National Marine Fisheries Service has provided us with unpublished data on the Sound epifaunal populations.

During the period between 1970 and 1974 additional power-plant monitoring and baseline benthic data from the central Sound are available from studies conducted on the north shore at Bridgeport, and at Northport and Shoreham on the south shore. Subtidal and intertidal infauna and epifauna surveys in Bridgeport Harbor were conducted during 1971 and 1972 (NAI, 1973b) as part of an operational baseline program. Ernst (1970) and D'Agostino and Colgate (1973) provided data on the nearshore subtidal communities and potential impacts from plant operation at Northport. Winter polychaete populations in areas in and out of the Northport thermal plume were investigated by Mulstray (1971). Hechtel (1970) conducted intertidal studies during plant operation at Northport. D'Agostino and Serafy (1974) provided baseline data on subtidal infauna and epifauna at Shoreham during 1973 and 1974.

In the western region of the Sound, baseline studies conducted at Stamford, Connecticut, for a proposed nuclear power plant provide infauna and epifauna data collected by techniques comparable to those used in New Haven (NAI, 1974c). Additional intertidal and shallow subtidal studies have been conducted in the vicinity of Stamford (Village Creek) to assess the impact of a minor fuel oil spill (NAI, 1974f).

In the eastern Sound inshore subtidal and intertidal studies were conducted at Niantic Bay for Northeast Utilities by Battelle (1977) and in the upper reaches of Niantic Bay for the City of New Haven (NAI, 1975b). Subtidal infaunal and epifaunal studies were also conducted at New London (Thames River) for a major dredging program (Department of the Navy, 1977, unpublished).

Exposure panel surveys were less common than other benthic programs. Clapp (1937) conducted an early study of fouling along the New England coast and included stations in New Haven. Subsequent to Clapp's work, exposure-panel data have been collected at New Haven and Niantic Bay from 1971 through the present (NAI, 1971, 1973a, 1974a, 1974b, 1975a, 1976a, 1977a, 1978; Battelle, 1977). Sampling frequency and techniques at the two sites are comparable. Compatible data have

also been collected in Stamford Harbor (NAI, 1974d) during 1972 and 1973. Exposure panels maintained in Bridgeport as part of the general baseline survey during 1972 were not comparable to those used in the other contemporaneous Sound studies; however, they do provide qualitative data on seasonal patterns of abundance and composition. Hillman (1973) used data from Stamford, Niantic Bay, and New Haven Harbor to examine environmental monitoring through the use of fouling panels and compared species richness in the three harbors.

The annotated bibliography which follows contains all references described in this literature overview as well as selected abstracts. The latter were chosen on the basis of their comparability to New Haven Harbor. The abstracts briefly describe the body of information available, the study location, and dates and sampling methods where applicable.

BIBLIOGRAPHY

Alperin, I. M. and R. H. Schaeffer. 1965. Marine fishes new or uncommon to Long Island. New York Fish and Game Jour. 12:1-16.

Amish, R. 1974. Preliminary assessment of the winter flounder, *Pseudopleuronectes americanus* population on Herod Point Shoal, Shoreham, Long Island with emphasis on reproduction. IN: Volume IV of the preoperational ecological monitoring program of the marine environs at LILCO Nuclear Power Generating Facility, Shoreham, Long Island, N.Y. 5 sections.

Evaluated the utilization of Herod Point Shoal as a winter flounder spawning or nursery area through measurement of indirect parameters such as occurrence, gonadal development and larval abundance.

Army Corps of Engineers. 1972. New Haven Harbor, Connecticut Maintenance Dredging.

Determined zinc, lead and copper content and chemical oxygen demand of dredge spoil. Alternatives for dredge spoil are discussed.

_____. 1973a. Final environmental statement: New Haven Harbor, Connecticut Maintenance Dredging. 171 pp and appendices.

A consideration of the suitability of the New Haven Dump Grounds as a regional dredge disposal site for central and western Long Island Sound.

_____. 1973b. Environmental statement, Coke Works Electric Generating Plant, New Haven Harbor, Connecticut.

Austin, H., M. Dickinson and C. Hickey. 1973. An ecological study of the ichthyofauna at the Northport power station, Long Island, New York prepared for LILCO by the Fisheries Oceanography Department of the New York Ocean Science Laboratory (NYOSL). 248 pp.

Ichthyoplankton data presented biweekly as the number of eggs and larvae per unit volume from surface and bottom tows, and egg-size by species. Adult fish-impingement data were presented as biomass and summary of the number of individuals impinged. Fishes from trawls, gills and seines were sexed, weighed, measured (measures and ranges presented), and stomach contents described. Fish results presented by species with information on distribution, brood habits and reproductive cycle. Zooplankton data included seasonal estimates of biomass along with species composition for copepods.

Austin, H. and O. Custer. 1974. Seasonal migration of striped bass in Long Island Sound as compiled from American Littoral Society tag returns. From a paper presented at Fish Tag Seminar, NYOSL, Montauk, N.Y. Dec. 14:24-35.

Austin, H.M., A. Sosnow and C. Hickey. 1974. The effects of temperature on the development and survival of the eggs and larvae of the Atlantic silversides (*Menidia menidia*). Section XI, Volume IV in Preoperational Ecological Monitoring Program at the Long Island Lighting Company, Shoreham, Long Island. 5 sections.

The study simulated the thermal effects of entrainment in the condenser of an electric power generating station on Atlantic silverside larvae.

Battelle Memorial Institute. 1973. Environmental monitoring program: service program marine ecology and biology, New Haven Harbor, Connecticut, May-October 1971. Prepared for Northeast Utilities Service Company. 16 sections.

This data report presents the results of monitoring programs similar to those presently conducted. The general sampling regime and sample stations were the same. Notable difference from current data include less detailed identification, especially for phytoplankton; fish eggs and larvae were not identified; and less intense waterfowl program.

Battelle Columbus Laboratories. 1977. A monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Annual Report Ecological and Hydrographic Studies 1976. Prepared for Northeast Utilities Service Company, Berlin, CT. 7 sections.

Primarily a compilation of raw and synthesized data from all programs conducted during 1976. Programs include: fouling, intertidal and subtidal benthos, zooplankton, ichthyoplankton, finfish, impingement, birds (osprey only), heavy metals, lobster and winter flounder population estimates and entrainment. Entrainment program section of report similar in scope and format to NAI programs (written by C. Fontneau). Data for most programs include material for years prior to 1976.

Battelle Columbus Laboratories. 1978. A monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Annual report of ecological and hydrographic studies, 1977. prepared for Northeast Utilities Service Company, Berlin, CT. 9 sections.

Bowman, M.J. 1977. Nutrient distribution and transport in Long Island Sound. Estuarine Coast. Mar. Sci. 5:531-548.

Caplan, R.I. 1976. Vertical distribution and reproduction of marine zooplankton. I: Winter patterns in Long Island Sound. 10 pp in preparation.

_____. 1977. Aquatic disposal field investigations, Eatons Neck, disposal site, Long Island Sound. Appendix E predisposal baseline conditions of zooplankton assemblages. Tech Rep. D-77-6. Army Corps of Engineers, WES, Vicksburg, MI. 104 pp.

Clapp. 1937. Marine piling investigation prepared by the New England Committee on marine piling investigation. 249 pp.

Information provided on fouling communities from 1934-1936 located on the northeast coast from northern Maine to Long Island Sound. Some tropical stations were included.

Clark, J. 1968. Seasonal movements of striped bass contingents of Long Island Sound and the New York Bight. Trans. Am. Fish. Soc. 97(4):320-343.

Connecticut Audubon Society. 1977. Christmas Bird Census.

Connecticut Department of Environmental Protection. Fish kill data for Connecticut Rivers and coastal waters, 1968 to present (1977) untabulated data.

Conover, S.M. 1956. Oceanography of Long Island Sound, 1952-1954. IV: Phytoplankton. Bull. Bingham Oceanogr. Coll. 15:62-112.

Custer, O. 1974. SCUBA observation. IN: Volume IV, Section VIII of the Preoperational Ecological Monitoring Program of the Marine Environs at the Long Island Lighting Company (LILCO) Nuclear Power Generating Facility, Shoreham, Long Island, New York. 5 sections.

SCUBA studies were designed to identify and quantify populations of fish, invertebrates and macroscopic algae on transects in and near offshore waters of Shoreham, Long Island.

D'Agostino, A. and W. A. Colgate. 1973. Infaunal invertebrates in the near shore waters of Long Island Sound benthos of Northport. LILCO Tech. Rept. SR-72-22. 31 pp.

D'Agostino, A. and D. K. Serafy. 1974. Benthic invertebrates of the nearshore waters. IN: Volume IV of the Preoperational Ecological Monitoring Program of the Marine Environs at LILCO Nuclear Power Generating Facility, Shoreham, Long Island, New York. 5 sections.

Study objectives were to obtain a quantitative seasonal census of benthic invertebrates from an area where an offshore thermal discharge was proposed and a control area. Additional objectives were to determine relative efficiencies of four benthic grab samplers and to determine if commercial quantities of lobsters, whelks and clams were present at Shoreham.

Deevey, G. B. 1956. Oceanography of Long Island Sound, 1952-1954. V. Zooplankton. Bull. Bingham Oceanogr. Coll. 15:113-155.

Department of the Navy. 1973. Environmental Impact Statement, New London, Conn. Volume 1. 215 pp and appended letters.

Duxbury, A. C. 1964. A hydrographic survey of New Haven Harbor 1962-1963. Connecticut Water Resources Bull. No. 3A. 19 pp.

EBASCO. 1970. New Haven Harbor Hydrographic Study Program. Prepared for United Illuminating Company, New Haven, Connecticut. 8 pp.

_____. 1971a. Environmental Report: Coke Works Site, June 1971. Prepared for United Illuminating Company, New Haven, Connecticut. 10 sections.

Review of background data collected to date. Data cover meteorology, air quality, population statistics, terrestrial and aquatic fauna and flora, noise generation, aesthetics and potential beneficial and negative impacts of the station.

_____. 1971b. 400 MW Coke Works generating plant effect of heated cooling water discharge on the temperature distribution of New Haven Harbor. Prepared for United Illuminating Company, New Haven, Connecticut. 19 pp.

Description of New Haven Harbor thermal regime and evaluation of the effect of the Coke Works Station discharge on the temperature distribution of New Haven Harbor. General Harbor isotherms developed and maximum seasonal temperatures projected.

Environmental Protection Agency, New York and Connecticut. 1975.
People and the Sound, water management. Prepared for the New
England River Basins Commission. 129 pp.

The report outlined the existing water supply situation and water
quality problems in Long Island Sound. Included a general dis-
cussion of major sources of pollution in Long Island Sound.

Equitable Environmental Health, Inc. 1977a. Port Jefferson Generating
Station Final Aquatic Ecology Report. Prepared for Long Island
Lighting Company, Hicksville, New York. 110 pp.

Ichthyoplankton entrainment, fish and epibenthic faunal impingement
and epibenthic fauna found in the thermal plume were examined at
the Port Jefferson Generating Station. Monthly impingement and
biweekly entrainment samples were supplemented by quarterly sam-
pling in near- and far-field plume areas. Quarterly sampling
included ichthyoplankton, trawls, crab pots, grabs, gill and trap
nets along with other commercial collection techniques (rakes,
tongs, etc.) designed to collect commercial species.

_____. 1977b. Northport Generating Station, Final Aquatic Ecology
Report. Prepared for Long Island Lighting Company, Hicksville, New
York. 50 pp.

Fish eggs and larval densities entrained in the plant cooling
system were compared with those in catches from near field waters
at the Northport, Long Island Generating Station.

_____. 1977c. Glenwood Generating Station Final Aquatic Ecology
Report. Prepared for Long Island Lighting Company, Hicksville, New
York. 112 pp.

Ichthyoplankton entrainment, fish and epibenthic faunal impingement
and community composition were examined in near- and far-field
stations in the thermal plume of the Glenwood Station. Quanti-
tative sampling programs were as follows: biweekly entrainment,
monthly impingement, and seasonal plume area studies (spring, sum-
mer and fall) except benthos which was sampled a single time
(fall). Benthic sampling was directed toward evaluation of commer-
cial species.

Ernst, E.J. 1970. Biological effects of thermal effluents, Northport,
New York. Part II: Flora and fauna of the jetty and deeper water
areas. Mar. Sci. Res. Cent., Stonybrook. Tech. Rept. pp. 53-74.

Federal Water Quality Administration. 1970. New Haven Harbor shellfish resource and water quality. U.S. Dept. of Interior, Northeast Region, Needham Heights, Mass. 22 pp.

Federal Power Commission Staff. 1975. People and the Sound, Power and the Environment prepared for the New England River Basins Commission. 129 pp.

A program was devised for supplying an adequate and reliable source of electrical energy with a minimum of environmental and social disruption.

Fisher, J. B. and P. L. McCall. 1973. The effect of environmental perturbations on benthic communities: an experiment in benthic recolonization and succession in Long Island Sound. Unpublished manuscript. Dept. Geology and Geophysics, Yale University. 33 pp.

Franz, D. 1976. Benthic molluscan assemblages in relation to sediment gradients in Northeastern Long Island Sound, Connecticut. Malacologia. 15(2):377-399.

Goodkind & O'Day and Fay, Spofford, and Thorndike. 1970. Report upon tidal studies of New Haven Harbor. Book I: New Haven Thermal Imagery. Prepared for City of New Haven Department of Public Works. 19 pp.

Delineation of surface thermal gradients of New Haven Harbor for 8 July 1970.

Goodkind & O'Day and Fay, Spofford, and Thorndike. 1970. Report upon tidal studies of New Haven Harbor. Book II: New Haven Thermal Imagery. Prepared for City of New Haven Department of Public Works. 12 pp.

Delineation of surface thermal gradients of New Haven Harbor for 9 July 1970.

_____. 1970b. Report upon tidal studies of New Haven Harbor. Prepared for City of New Haven Department of Public Works. 19 pp.

IR overflights showed tidal patterns and indicated that the inner harbor is large enough to produce adequate dilution of pollution loads.

_____. 1970c. Summary and recommendations of reports upon facilities for secondary treatment of sewage and industrial wastewaters. Report No. 3. Prepared for City of New Haven Department of Public Works. 23 pp and appended data.

This study evaluated flow rates, site location, mode of treatment, facilities, outfall locations, construction and operational costs with regard to the final design of secondary sewage treatment facilities in New Haven. The final recommendation was for construction of the facility at the Boulevard site on Long Wharf.

Hardy, C. D. 1972a. Movement and quality of Long Island Sound waters, 1971. SUNY Mar. Sci. Res. Ctr. Stonybrook. Tech. Rept. No. 17. 64 pp.

_____. 1972b. Hydrographic data report: Long Island Sound 1970. Part II. SUNY Mar. Sci. Res. Cent., Stonybrook. Tech. Rept. No. 13. 20 pp.

Water quality parameters (temperature, salinity, chlorophyll *a*, turbidity, NH_3 , ortho PO_4 and urea) were measured in Long Island Sound during periods of maximum runoff and maximum temperatures and stratification (April and August 1971).

Parameters measured on the Marine Science Research Center cruise of 5-7 October 1970 include temperature, salinity, nutrients, DO, and chlorophyll *a*. Data were collected on a continuous basis and at discrete stations throughout the Sound.

Hardy, C. D. and P. K. Weyl. 1970. Hydrographic data report: Long Island Sound 1970 Part I. SUNY Mar. Sci. Res. Cent., Stonybrook. Tech. Rep. No. 6. 96 pp.

Hydrographic data report for cruises conducted by the Marine Sciences Research Center in western Long Island Sound between 28 January and 21 April 1970. Parameters measured were salinity, temperature, reactive phosphate, inorganic nitrogen, oxidizable ammonia and chlorophyll *a*. Data were collected on a continuous basis at a depth of 1 m using a flow through system. The majority of the data were collected west of the Bridgeport/Port Jefferson area. Data collected east of this line were primarily from the southern side of the Sound.

_____. 1971. Distribution of dissolved oxygen in the waters of western Long Island Sound. SUNY Marine Science Research Center, Stonybrook. Tech. Rept. No. 11. 37 pp.

Surveys were conducted during 7-15 August and on 5 October 1970 in western Long Island Sound.

Hechtel, G. J. 1970. Biological effects of thermal effluents, Northport, New York. Part 1. Intertidal benthic invertebrates. Mar. Sci. Res. Cent., Stonybrook, New York. Tech. Rept., pp. 1-52.

Soft and hard substrate intertidal faunal assemblages were sampled to determine thermal discharge impact and relation to other Long Island Sound areas.

Hillman, R. E. 1973. Environmental monitoring through the use of exposure panels. IN: Fisheries and Energy Production: A Symposium. (ed.) S. B. Saila. D. C. Heath and Company, Lexington, MA. pp. 55-76.

This report presents a comparison of exposure panel data from Niantic Bay, New Haven Harbor and Stamford Harbor sampled from October 1971 through September 1972. Sampling methods were similar for all studies.

Hillman, R. E., N. Davis, and S. Wennemer. 1977. Abundance, diversity and stability in shore-zone fish communities in an area of Long Island Sound affected by the thermal discharge of a nuclear power plant. *Estuar. Coast. Mar. Sci.* 5:355-381.

Jay, D. A. and M. J. Bowman. 1975. The physical oceanography and water quality of New York Harbor and western Long Island Sound. SUNY Mar. Sci. Res. Ctr., Stonybrook, New York, Tech. Rep. No. 23. 71 pp.

The majority of this report was related to literature reports of circulation and hydrology of New York Harbor and adjacent rivers. Material concerning Long Island Sound was limited to a brief overview.

Jeffries, H. P. and W. C. Johnson. 1974. Seasonal distributions of bottom fishes in the Narragansett Bay area, seven-year variation in the abundance of winter flounder (*Pseudopleuronectes americanus*). *J. Fish. Res. Bd. Can.* 31:1057-1066.

Jensen, A. C. 1977. New York Marine Fisheries: Changing needs in a changing environment. *New York Fish and Game Jour.* Vol. 24(2): 99-128.

Lawler, Matusky and Skelly Engineers. 1975a. Norwalk Harbor Station, Thermal Plume Studies. Prepared for Connecticut Light and Power Company, Berlin, Connecticut. 15 pp and appendices.

_____. 1975b. Devon Station, Thermal Plume Studies. Prepared for Connecticut Light and Power Company, Berlin, Connecticut. 21 pp and appendices.

_____. 1975c. Middletown Station, Thermal Plume Studies. Prepared for the Hartford Electric Light Company, Berlin, Connecticut. 9 pp and appendices.

_____. 1976. Montville Station, Thermal Plume Studies. Prepared for Connecticut Light and Power Company, Berlin, Connecticut. 13 pp and appendices.

Marine Sciences Research Center, SUNY, Stonybrook, New York. 1970. Biological effects of thermal pollution, Northport, New York. SUNY Mar. Sci. Res. Ctr., Tech. Rpt. No. 3. 107 pp.

Investigated the impact of thermal discharges on hard and soft substrate intertidal and subtidal faunal and floral communities.

McCall, P. L. 1977. Community patterns and adaptive strategies of the infaunal benthos of Long Island Sound. J. Mar. Res. 35:221-266.

McCracken, F. D. 1963. Seasonal movements of the winter flounder, *Pseudopleuronectes americanus* (Walbaum) on the Atlantic coast. J. Fish. Res. Bd. Can. 20(2):551-586.

Mulstray, R. 1971. Winter survey of polychaete fauna. IN: Studies on the effects of a steam-generating station on the marine environment at Northport, New York. Mar. Sci. Res. Ctr., SUNY, Tech. Rept. 9:91-104.

New England River Basins Commission. 1975. People and the Sound: A plan for Long Island Sound. 225 pp.

The Commission outlined an economically and environmentally sound plan for the development of Long Island Sound. Included are EPA restrictions on wastewater facility grants from EPA and environmental impact statements for some projects.

New York Ocean Science Laboratory. 1974. Preoperational ecological monitoring program of the marine environs at LILCO, Shoreham Nuclear Power Station, Shoreham, New York. Volume 1: Physical and Chemical Oceanography. Prepared for LILCO, Hicksville, New York. 2 sections.

_____. 1974. Preoperational ecological monitoring program of the marine environs at LILCO, Shoreham Nuclear Power Station, Shoreham, New York. Volume II: Phytoplankton, zooplankton and ichthyoplankton. prepared for LILCO, Hicksville, New York. 3 sections.

This data report provides information on seasonal and spatial variability in plankton populations during 1973 off the Shoreham, New York area. Sampling was conducted monthly and biweekly at five stations depending upon program and season. Quarterly, diurnal sampling at 20 stations. Data presented in tables and figures, little raw data, statistical comparisons limited.

_____. 1974. Preoperational ecological monitoring program of the marine environs at LILCO, Shoreham Nuclear Power Station, Shoreham, New York. Volume III: Fishery ecology. Prepared for LILCO, Hicksville, New York. 1 section.

Programs conducted during 1973 include shore-zone seines, trawls and gill nets. Sampling was conducted monthly with biweekly efforts during critical periods -- April, May, June, September and October. Available data include standard lengths, age, stomach contents and weight, total body weight and gonadal index. In addition, horizontal and vertical distributions of more common species are plotted for the Shoreham area.

New York State Department of Environmental Conservation. 1977. New York State midwinter aerial waterfowl survey in Long Island Sound. 5 pp.

Normandeau Associates, Inc. 1971. Ecological considerations of the Coke Works Site, New Haven Harbor, Connecticut. Prepared for the United Illuminating Company, New Haven, Connecticut. 64 pp.

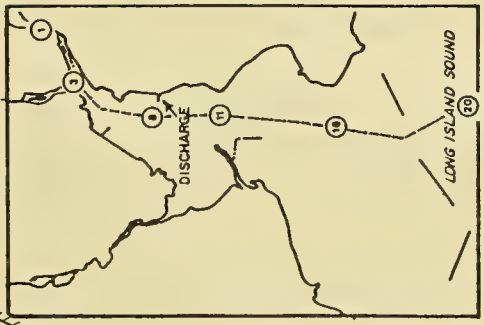
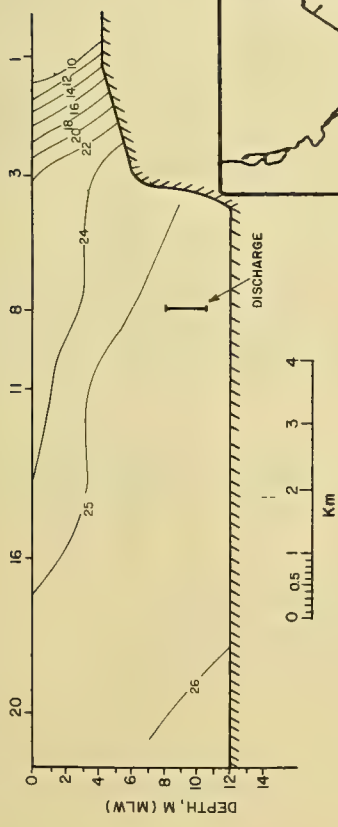
_____. 1971. A bathythermographic survey of the receiving waters adjacent to the English Generating Station, New Haven, CT., July 1971. Prepared for United Illuminating Company, New Haven, CT. 29 pp.

Data report described the thermal regime in the Mill River during various tidal conditions in July 1971.

_____. 1972. Addendum 12 of environmental report: Coke Works site, June 1971. Marine Sediments, New Haven Harbor, Connecticut. Results of analyses and proposals for dredge spoil disposal. Prepared for United Illuminating Company, New Haven, CT. 134 pp.

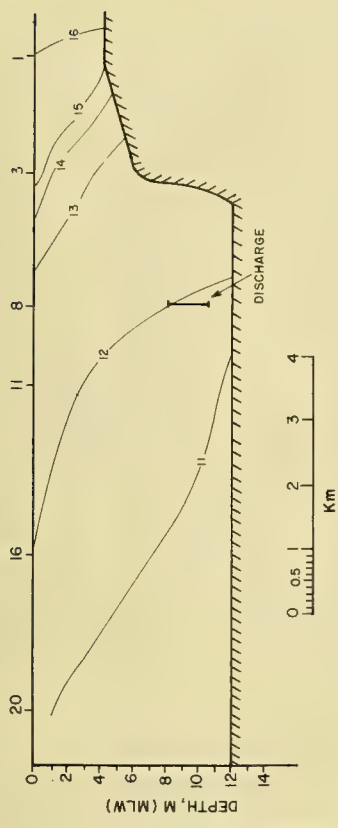
Determined quality of sediments in the vicinity of the Coke Works site and evaluated potential spoil disposal schemes. Includes metal and organic analyses.

EBB TIDE
MAY 1977



SALINITY (PPT)

TEMPERATURE (°C)



EBB TIDE
JUNE 1977

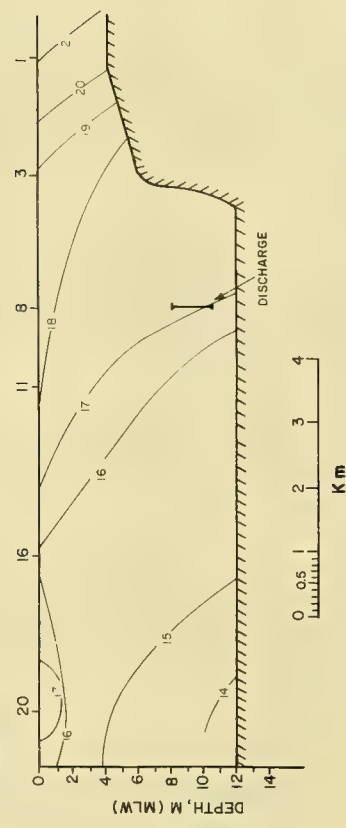
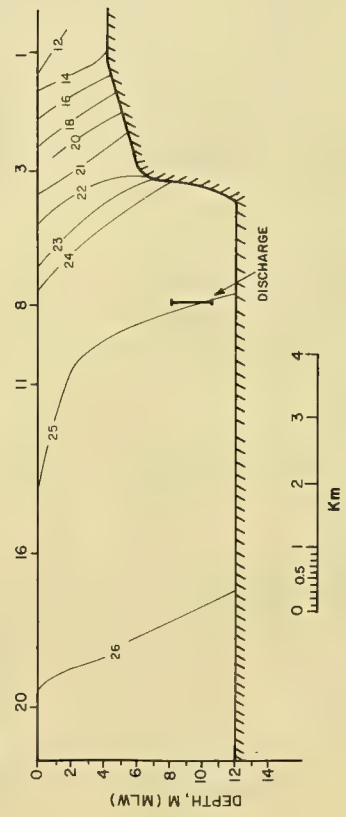
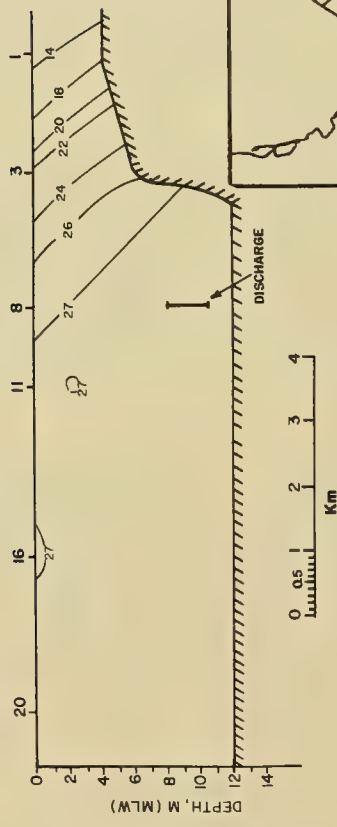


Figure 3-5. (Continued)

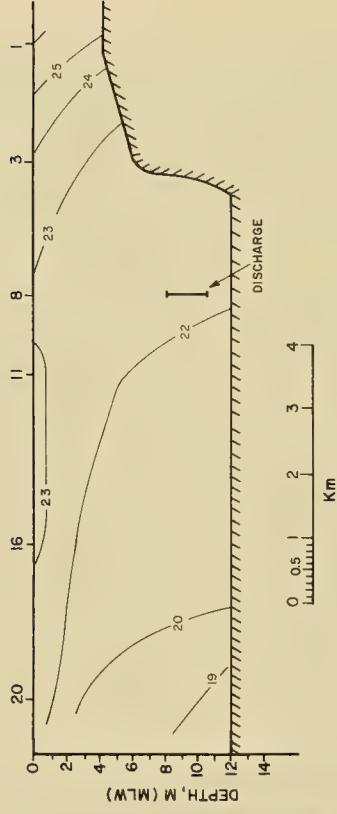
Continued

EBB TIDE
JULY 1977

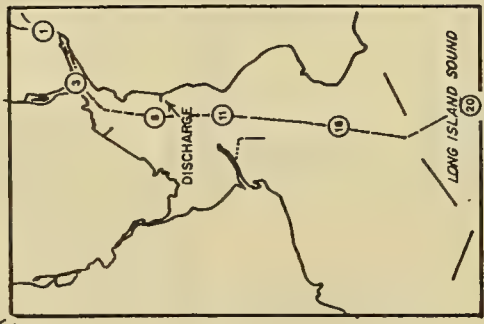


SALINITY (PPT)

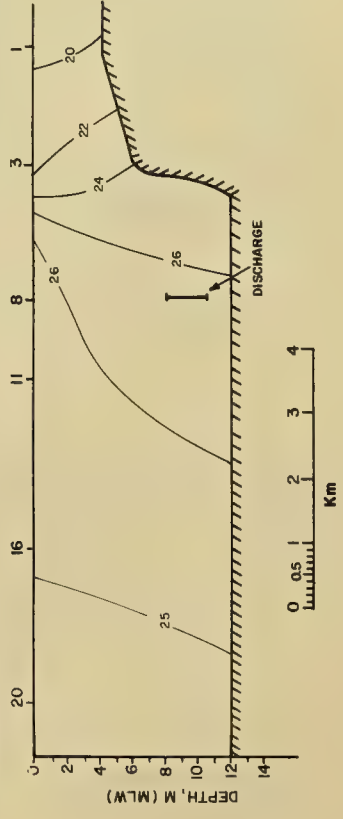
EBB TIDE
JULY 1977



TEMPERATURE (°C)



EBB TIDE
AUGUST 1977



EBB TIDE
AUGUST 1977

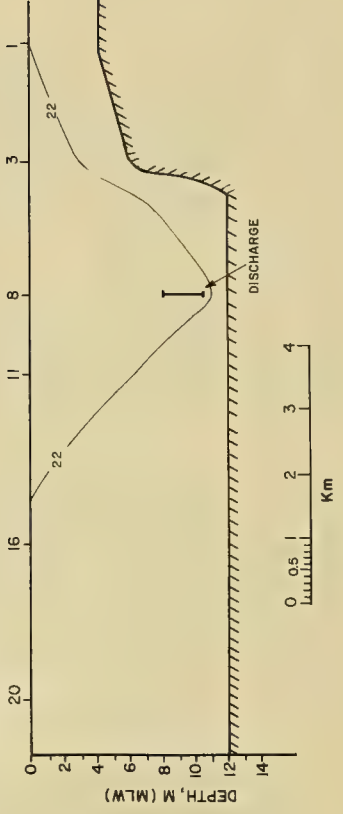


Figure 3-5. (Continued)

Continued

_____. 1976a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1975 prepared for the United Illuminating Company, New Haven, Connecticut. 312 pp.

_____. 1976b. New Haven Harbor Thermal Regime during operation of the New Haven Harbor Station, September 1975 prepared for the United Illuminating Company, New Haven, Conn. 31 pp.

_____. 1976c. New Haven Harbor Station Condenser Tube Fouling Study (draft) prepared for the United Illuminating Company, New Haven, Connecticut. 12 pp.

Determined the nature of the fouling material in condenser tubes of the New Haven Harbor Station and whether chlorinating to levels within EPA effluent limitations would control the problem. Surface films and accumulated condenser tube sludge were sampled on April 7, 1976.

_____. 1976d. New Haven Harbor Station Ecological Monitoring Studies, 1976: Acute Toxicity Studies prepared for the United Illuminating Company, New Haven, Conn. 64 pp.

Sufficient information in the literature on heat tolerance was found for all species to conclude that no substantial toxic effects were expected from station operation. Species selected for the study were: *Skeletonema costatum*, *Acartia clausi*, *Acartia tonsa*, *Crangon septemspinosa*, *Crassostrea virginica*, *Homarus americanus*, *Mytilus edulis*, *Teredo navalis*, *Pseudopleuronectes americanus*, *Pomatomus saltatrix*, *Cynoscion regalis*, *Brevoortia tyrannus*, *Anchoa mitchilli*, *Morone saxatilis*.

_____. 1977a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1976 for the United Illuminating Company, New Haven, Connecticut. 376 pp.

_____. 1977b. Thermal surveys New Haven Harbor Summer and Fall, 1976 prepared for the United Illuminating Company, New Haven, Connecticut. 70 pp.

The study defined the thermal plume of the New Haven Harbor Station as required by the National Pollutant Discharge Elimination (NPDES) Permit to Discharge. Surveys by Rhodamine WT and 3-D temperature sampling were conducted in July, August and October 1976.

- _____. 1978. New Haven Harbor Station Ecological Monitoring Study, New Haven Harbor, Connecticut Annual Report 1977 prepared for the United Illuminating Company. 359 pp.
- _____. 1979. In preparation. New Haven Sewage Treatment Facility siting environmental assessment prepared for the City of New Haven, New Haven, Connecticut.
- Northeast Utilities Service Company. 1976. Data report of fin- and shellfish impinged from August 1975 to August 1976 at Devon Station, Middletown Station, Norwalk Harbor, and Montville Station. 37 pp.
- Nuzzi, R. 1977. Aquatic disposal field investigations, Eatons Neck disposal site, Long Island Sound. Appendix F predisposal baseline conditions of phytoplankton assemblages. Tech. Rep. D-77-6, Army Corps of Eng., WES, Vicksburg, MI. 42 pp.
- _____. 1977. Aquatic disposal field investigations, Eatons Neck disposal site, Long Island Sound. Predisposal baseline conditions of zooplankton assemblages. Tech. Rep. D-77-6, ACE. Vicksburg, MI. 104 pp.
- Pearcy, W. G. 1962. Ecology of an estuarine population of winter flounder, *Pseudopleuronectes americanus* (Walbaum). Parts I-IV. Bull. Bingham. Ocean. Coll. Vol. 18(1). 125 pp.
- Pearcy, W. G. and S. W. Richards. 1962. Distribution and ecology of fishes of the Mystic River estuary, Connecticut. Ecol. 45:248-259.
- Perlmutter, A. 1971. Ecological study of the aquatic environs of the proposed nuclear power station of LILCO at Shoreham: 1970-1971 and summary 1968-1971 prepared for LILCO. 136 pp.
- Powell and Schwartz. 1977. Distribution of Paralichthid flounders (Bothidae Paralichthys) in North Carolina estuaries. Ches. Sci. 18:334-339.
- Prince, J. S. and L. A. Melville. 1970. New Haven Report, Algal. June August 1970 unpublished 5 pp.
- Examination of macroalgae at four hard-substrate sites in New Haven Harbor in June, July and August 1970.

Quirk, Lawler and Matusky Engineers. 1969. New Haven Harbor effect of increased waste treatment and outfall location on water quality. Prepared for State of Connecticut Water Resources Commission. mimeo 25 pp.

Determined the effect of various sewage treatment schemes on New Haven Harbor water quality (BOD loadings and DO levels) based on a steady-state mathematical model.

Raytheon Company. 1970. New Haven Harbor plankton survey, April-May 1970. Prepared for United Illuminating Company, New Haven, CT. 49 pp.

Hydrographic delimitation of thermocline (at 5 meters) and water quality regimes in the inner and outer harbor. Parameters measured include temperature, salinity, DO and turbidity. Zooplankton comparisons (numbers available) by station and date were made, as well as an examination of the efficiency of #10 and #20 mesh nets (#10 net deemed more efficient at capturing larger zooplankters).

Raytheon Company. 1970. New Haven Harbor Ecological Survey, Data Report, June-December 1970. Prepared for United Illuminating Company, New Haven, CT. 179 pp.

Data were presented but not discussed for June-December 1970. Programs were conducted as at the present time with minor changes, in particular station locations, sampling regime, the alteration of some programs and the presence of programs no longer conducted as part of the regular monthly programs: macroalgae, *Mya* study, Thorsen bottles and aerial thermal overflights.

_____. 1971. New Haven Harbor Ecological Survey, Data Report, December 1970-April 1971. Prepared for United Illuminating Company, New Haven, CT. 11 sections.

Data report of baseline survey of biological communities and associated hydrographic parameters in New Haven Harbor sampling regime same as Raytheon 1970.

Reid, R. N., A. B. Frame and A. F. Drexler. Unpublished. Environmental baseline studies in Long Island 1972-1975. National Marine Fisheries Service, NOAA, Sandy Hook, New Jersey. 11 pp and appendices.

Data report, no further analysis completed on benthic infauna or sediment and water chemistry. Data available on benthos from July 1972 cruise,; in addition, water quality including surface and bottom temperature, salinity, dissolved oxygen, NO₂, NO₃, NH₄, urea and ortho PO₄ data were collected summer 1972, April and September 1973. Sediments, from July 1972, include grain size, carbonates and organic content. Stations of interest include 52, 60, 61, 68 (New Haven area), 71 (Shoreham) and 48 and 49 (Port Jefferson).

Rhoads, D.C. 1972. The environmental consequences of dredge spoil disposal in central Long Island Sound: I. Benthic biology of the New Haven dump site. Unpublished Report to U.S. Army Corps of Engineers and the United Illuminating Co. 40 pp.

_____. 1973. The environmental consequences of dredge spoil disposal in central Long Island Sound. II: Benthic biology of the New Haven Harbor Channel and northwest control site. Prepared for United Illuminating Company, New Haven, CT. 61 pp.

Provided baseline data on benthic infaunal community at a proposed dredge site and a control site adjacent to the New Haven dumping ground.

_____. 1973b. The environmental consequences of dredge spoil disposal in central Long Island Sound. III: Benthic biology of the south control site, 1972. Prepared for United Illuminating Company, New Haven, CT. 44 pp.

Baseline data provided on benthic infaunal community at a proposed control site near the New Haven dumping ground. Data on bivalve and gastropod biomass presented. Polychaete data not completed. Raw data presented in appendix.

_____. 1973c. The environmental consequences of dredge spoil disposal in central Long Island Sound: IV. Benthic sampling Guilford Harbor dredging project predredging study. Unpublished Report to U.S. Army Corps. of Engineers. 15 pp.

_____. 1973d. The environmental consequences of dredge spoil disposal in central Long Island Sound: V. Benthic biology of the Milford, Branford, and Guilford Dump Grounds. Unpublished Report to U.S. Army Corps of Engineers and United Illuminating Co. 38 pp.

_____. 1973e. The environmental consequences of dredge spoil disposal in central Long Island Sound: VIII. Benthic biology of the New Haven ship channel, dump site, south and northwest control sites, Summer 1973. Unpublished Report to U.S. Army Corps of Engineers and the United Illuminating Co. 64 pp.

_____. 1974a. The environmental consequences of dredge spoil disposal in central Long Island Sound: VIII. Changes in spatial and temporal abundance patterns of benthic molluscs sampled from New Haven Harbor Dump Site, South and Northwest Control Sites, 1972-1973 (pre-dump) baseline). Unpublished Report to U.S. Army Corps of Engineers and the United Illuminating Co. 49 pp.

_____. 1974b. The environmental consequences of dredge spoil disposal in central Long Island Sound: IX. Benthic biology of the New Haven Harbor ship channel, New Haven dump site, new south control and northwest control sites, February-March, 1974 (during dredging and dumping operations). Unpublished Report to U.S. Army Corps of Engineers. 50 pp.

_____. 1974c. The environmental consequences of dredge spoil disposal in central Long Island Sound: X. Benthic biology of the New Haven Harbor ship channel, New Haven dump site, new south control and northwest control sites, July, 1974 (postdredging and dumping). Unpublished Report to U.S. Army Corps of Engineers, 79 pp.

_____. 1975. The environmental consequences of dredge spoil disposal in Central Long Island Sound: XIII. The use of bivalve depth assemblages to recognize environmental change in central Long Island over the past 150 years. Unpublished Report to U.S. Army Corps of Engineers. 41 pp.

Rhoads, D. C. and A. D. Michael. 1975. Benthic monitoring study for the United Illuminating Company Coke Works Site Power Plant. Report I: Baseline data, 1974. Unpublished report. 22 pages and appended data sheets.

Provided baseline information for monitoring the effects of thermal discharge from the New Haven Harbor Station on benthic population structure at Morris Cove and inner harbor stations.

_____. 1976. Benthic monitoring study for the United Illuminating Company Coke Works site power plant. Report II: Benthic monitoring during plant testing and early operation 1975. Unpublished report. 8 pages and appended data sheets.

_____. 1977. Benthic monitoring study for the United Illuminating Company Coke Works site power plant. Report III: Benthic monitoring during plant testing and early operations 1976. Unpublished report. 10 pages and appended data sheets.

_____. 1978. Benthic monitoring study for the United Illuminating Company Coke Works Site Power Plant. Report IV: Benthic monitoring during plant testing and early operation 1978. Unpublished report. 11 pages and appended data sheets.

Rhoads, D. C., R. C. Allen, and M. B. Goldhaber. 1975. The influence of colonizing benthos on physical properties and chemical diagenesis of the New Haven dump site. IN: Environmental Consequences of Dredge Spoil Disposal in Central Long Island Sound, XI. Unpublished report to U.S. Army Corps of Engineers, 45 pp.

Sampling from June 1974 through April 1975 at the New Haven dump site examined the influence and succession of colonizing benthos on physical properties and chemical diagenesis.

Richards, S. W. 1959. Pelagic fish eggs and larvae of Long Island Sound. Bull. Bingham Oceanogr. Coll., 95-124.

Present survey data from 1954-1955 with comparisons to the 1952-1953 survey. Data provided information on spatial and temporal distribution on eggs and larvae of 22 species. Variations in abundance were related primarily to dominant species, chiefly *Anchoa*, the most common species encountered. Data were presented by species with descriptions of distributions along with size of eggs and larvae.

Richards, S. W. 1963. The demersal fish population of Long Island Sound. I: Species composition and relative abundance in two localities, 1956-1957. Bull. Bingham Oceanogr. Coll. 18(2):5-31.

Riley, G. A. and S. M. Conover. 1956. Oceanography of Long Island Sound, 1952-1954. III: Bull. Bingham Oceanogr. Coll. 15-47-61.

Sanders, H. L. 1956. Oceanography of Long Island Sound, 1952-1954. The biology of marine bottom communities. Bull. Bingham Oceanogr. Coll. 15:345-414.

Schaeffer, R. H. 1967-1972. Species composition, size and seasonal abundance of fish in the surf waters of Long Island, New York. Fish and Game Jour. 14(1):1-46.

Stone and Webster Engineers. 1972. Temperature prediction model for Long Island Sound. Prepared for the Long Island Sound study group. 5 sections.

TRC Service Corporation. 1967. Preliminary site evaluation, Fort Hale, New Haven, Connecticut prepared for the Northeast Utilities Service Company, Berlin, CT. 75 pp.

Historical data covering meteorology, water resources, geology, hydrology, aquatic ecology, air quality and socio-economic parameters for the Fort Hale/Coke Works site and New Haven area.

Turekian, K., R. Gordon and A. Michael. 1974. Report on heavy metal studies conducted in New Haven Harbor during June 1974. Prepared for United Illuminating Company, New Haven, CT. 3 pp.

Data report for sampling period June 1974. Metals examined were copper, lead, zinc, cadmium and mercury at Morris Cove and Harbor Station sites.

United Illuminating Company. 1977. New Haven Harbor Station #1 impingement data. Mimeo, raw data.

_____. 1977. Bridgeport Harbor Station impingement data. January-December 1977, mimeo, raw data.

_____. 1970. The United Illuminating Company Thermal Discharge. Mimeo, 28 pp.

U.S. Coast Guard. Oil spill records and pollution case log book. U.S. Coast Guard, New Haven Group. Coast Guard files.

U.S. Fish and Wildlife Service and National Marine Fisheries Service. 1975. People and the Sound, Fish and Wildlife prepared for the New England River Basins Commission. 56 pp.

The report assembled information on the ecosystem of the Long Island Sound (LIS) region, its fishery and its wildlife and recommended measures for uses of these resources that will be compatible on an environmental, economic and social basis.

U.S. Geologic Survey. 1970-1973; 1971-1973. Water resources data for Connecticut. U.S.G.S. Water-data report. CT-71, 72, 73-1, 75-1. 4 volumes.

Valenti, R. J. 1974. The effects of temperature and thermal shocks on the development of embryos and larvae of the winter flounder (*Pseudopleuronectes americanus*). Section X, Volume IV of Preoperational Ecological Monitoring Program at the Long Island Lighting Company Shoreham Nuclear Power Station, Shoreham, Long Island, New York. 5 sections.

Studies determined thermal tolerances of winter flounder larvae and embryos. Test temperatures and duration times were representative of increased temperature ranges due to power plant condensers and entrainment times for larvae within the condensers.

- Warfel, H. E. and D. Merriman. 1944. Studies on the marine resources of southern New England. I: An analysis of the fish populations of the shore zone. Bull. Bingham Oceanogr. Coll. 9(2):1-91.

The survey on the shore-zone fish populations of New Haven Harbor was conducted from July 1942 through June 1943. Sampling included biweekly seine collections from the Morris Cove region of New Haven Harbor. Data presented for the more common species, include length-frequency curves and life cycle information. Fish abundance data were also compared to water temperature, salinity and interrelationship with prey availability and trophic structure of the community. Temperature and prey availability affect population size with low winter temperatures apparently excluding all species.

- Westman, J. R. and R. F. Nigrelli. 1955. Preliminary studies of menhaden and their mass mortalities in Long Island and New Jersey waters. N.Y. Fish and Game Jour. 2:142-153.

- Weyl, P. K. 1971. Temperature distribution of the heated effluent from the Northport Power Station (LILCO) in Long Island Sound. Tech. Rept. No. 10, Marine Science Research Center, SUNY at Stonybrook, New York. 25 pp.

Three surveys were conducted to define the configuration of a thermal plume resulting from the discharge of heated effluent into Long Island Sound. Samples were taken at depths of 15, 50 and 85 cm in May 1969, February and July 1970.

- Williams, G. C. 1971. Studies on the effects of a steam electric generating plant in the marine environment at Northport, N.Y. SUNY, Mar. Sci. Res. Ctr. Tech Rept. No.9. 42 pp.

- Williams, G. C., D. C. Williams, and R. J. Miller. 1973. Mortality rates of planktonic eggs of the cunner, *Tautogolabrus adspersus*, in Long Island Sound. IN: Proceedings of a workshop on eggs, larval and juvenile stages of fish in Atlantic Coast estuaries. USDC, NOAA, NMFS Tech. Publ. No. 1. pp 181-195.

The natural survival rates of fish eggs were examined in the Old Field Point region of Long Island (longitude 73°08' west central region of Sound).

- Young, J.D. 1975. Menhaden and power plants: a growing concern. NMFS Paper No. 1094, pages 19-23.

A review of literature of the impact of heat and cold shock, entrainment and impingement on menhaden.

Young, J.S. and I. Gibson. 1973. Effect of thermal effluent on migrating menhaden. Mar. Pollut. Bull., Vol. 4:44-95.

An investigation into impact of heated effluents on menhaden.

Zawacki, C.S. and P.T. Briggs. 1976. Fish investigations in Long Island Sound at a nuclear power station site at Shoreham, New York. N.Y. Fish and Game Jour. 23(1):34-50.

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

3.0 HYDROGRAPHY OF NEW HAVEN HARBOR AND PHYSICAL/CHEMICAL
EFFECTS FROM OPERATION OF NEW HAVEN HARBOR STATION

By Michael Tubman,
David Pease and Allan Hartwell
Normandeau Associates, Inc.
Bedford, N. H.

TABLE OF CONTENTS

	PAGE
<i>INTRODUCTION.</i>	3-1
<i>Study Area.</i>	3-1
<i>General Hydrography of New Haven Harbor</i>	3-2
<i>Hydrology of the New Haven Harbor Drainage Basin.</i>	3-3
<i>General Patterns of Circulation in Long Island Sound.</i>	3-5
<i>Climatology</i>	3-5
<i>Previous Studies - New Haven Harbor</i>	3-6
<i>Previous Studies - Long Island Sound.</i>	3-8
<i>Environmental Studies at Other Power Plant Sites.</i>	3-9
 <i>METHODS</i>	 3-10
<i>Monthly Surveys</i>	3-10
<i>Continuous Monitoring Station</i>	3-12
 <i>DESCRIPTION OF NEW HAVEN HARBOR HYDROGRAPHY</i>	 3-12
<i>Estuarine Classification and Harbor-Wide Circulation Patterns</i>	3-13
<i>Salinity Distribution</i>	3-17
<i>Temperature Distribution for the Sample Year.</i>	3-28
<i>Temperature-Salinity: Patterns of Density Changes During the Sample Year</i>	3-32
<i>Dissolved Oxygen Distribution</i>	3-34
<i>pH Distribution</i>	3-35
<i>Transparency.</i>	3-41
<i>Spatial Variability Patterns</i>	3-41
<i>Comparisons Among Study Years</i>	3-52
<i>Summary: Characterization of New Haven Harbor Hydrography.</i>	3-55
 <i>ANALYSIS OF IMPACT.</i>	 3-57
<i>Modification of Local Current Patterns.</i>	3-58
<i>Modification of the Thermal Regime in the Harbor.</i>	3-75
<i>Changes in Dissolved Oxygen Concentration</i>	3-91

	PAGE
<i>Increased Turbidity</i>	3-96
<i>Summary of Impacts.</i>	3-99
<i>LITERATURE CITED -- HYDROGRAPHIC.</i>	3-101

LIST OF FIGURES

	PAGE
3-1. Estimated mean monthly runoff, 1967-1977.	3-4
3-2. Monthly precipitation and monthly means of daily temperature maxima and minima in Bridgeport, Connecticut area, with predicted runoff for New Haven Harbor watershed	3-7
3-3. Physical/chemical data collected from May 1971 to October 1977.	3-11
3-4. Composite flood (a) and ebb (b) tide currents, New Haven Harbor (From Duxbury, 1963)	3-16
3-5. Salinity and temperature transects along the axis of the New Haven Harbor channel, ebb tide, November 1976-October 1977	3-18
3-6. Surface and bottom, flood and ebb tide salinity contours for November 1976 and February, May, August, October 1977.	3-24
3-7. Surface and bottom, flood and ebb tide temperature contours for November 1976 and February, May, August, October 1977.	3-29
3-8. Temperature vs. salinity, Stations 3 and 20, surface and bottom, flood and ebb tides, October 1976-October 1977.	3-33
3-9. Monthly surface and bottom dissolved oxygen (mg/l) by tide and depth, Stations 3, 8 and 20, from May 1971 through October 1977	3-36
3-10. Monthly surface and bottom pH on ebb and flood tide, Stations 3 and 20, from May 1971 through October 1977 . .	3-39
3-11. Monthly surface and bottom salinity and temperature data from Station 3, flood and ebb tides, in New Haven Harbor, Connecticut	3-42
3-12. Monthly surface and bottom salinity and temperature data from Station 8, flood and ebb tides, in New Haven Harbor, Connecticut	3-44

3-13.	Monthly surface and bottom salinity and temperature data from Station 20, flood and ebb tides, in New Haven Harbor, Connecticut.	3-46
3-14.	Vector sum of tide and intake current velocities at the entrance to the intake channel.	3-59
3-15.	Definition sketch of University of Florida model tests (From UFLA, 1972)	3-61
3-16.	Velocity distribution along axis of plume (UFLA, 1972).	3-62
3-17.	Surface isotherms, ΔT ($^{\circ}F$) from UFLA, 1972.	3-67
3-18.	Projected surface ΔT ($^{\circ}F$) based on dye concentrations, high water slack, August 25, 1976, thermal survey	3-68
3-19.	Projected surface ΔT ($^{\circ}F$) based on dye concentrations, mid ebb current, August 24, 1976, thermal survey.	3-69
3-20.	Transect for determining the tidal input of momentum to Section A during flood tide.	3-71
3-21.	EBASCO model segments (EBASCO, 1971).	3-76
3-22.	Full depth tidal cycle average water temperature increases ($^{\circ}F$) (EBASCO, 1971)	3-78
3-23.	EBASCO dye study stations (EBASCO, 1971).	3-80
3-24.	Isotherms (Δt $^{\circ}F$) from October 13, 1976, thermal survey at low water slack.	3-85
3-25.	Isotherms (Δt $^{\circ}F$) from October 13, 1976, thermal survey during maximum flood current.	3-86
3-26.	Isotherms (Δt $^{\circ}F$) from October 13, 1976, thermal survey at high water slack	3-87
3-27.	Isotherms (Δt $^{\circ}F$) from October 13, 1976, thermal survey during maximum ebb currents	3-89
3-28.	Post-operational bathymetric survey of discharge area (USACE, January 1978; unpublished).	3-97
3-29.	Preoperational bathymetric survey of discharge area (USACE, May 1974; unpublished).	3-98

LIST OF TABLES

	PAGE
3-1. SUMMARY OF CLIMATOLOGICAL AND HYDROGRAPHIC CONDITIONS, 1970-1977.	3-53
3-2. MAXIMUM CROSS-SECTIONAL AREA OF DISCHARGE FLOW-AWAY AT SELECTED VELOCITIES	3-63
3-3. RESULTS OF NAI HYDROGRAPHIC SURVEY DURING DECEMBER 1977 - EBB TIDE.	3-65
3-4. FULL DEPTH AVERAGE TEMPERATURE INCREASE, MAY 1970. . . .	3-81
3-5. FULL DEPTH AVERAGE TEMPERATURE INCREASE, SEPTEMBER 1978.	3-82
3-6. SUMMARY OF HONEYWELL CONTINUOUS MEAN ANNUAL WATER TEMPERATURE DATA FOR PREOPERATIONAL AND POST-OPERA- TIONAL CONDITIONS.	3-83
3-7. PROPERTIES OF A HYPOTHETICAL WATER COLUMN, CHARACTER- ISTIC OF WINTER CONDITIONS	3-87
3-8. PERCENT SATURATION OF DISSOLVED OXYGEN AT THE SURFACE DURING 1976 AT EBB TIDE.	3-95

3.0 HYDROGRAPHY OF NEW HAVEN HARBOR AND PHYSICAL/CHEMICAL EFFECTS FROM OPERATION OF NEW HAVEN HARBOR STATION

By Michael Tubman, David Pease and Allan Hartwell
Normandeau Associates, Inc.
Bedford, N. H.

INTRODUCTION

The purpose of this section is to describe the results of more than seven years of intensive, year-round hydrographic studies in New Haven Harbor. The data, which were collected as part of UI's ongoing ecological monitoring studies for the New Haven Harbor Station, have been used in combination with various other studies of the Harbor and adjacent waters of Long Island Sound to present a comprehensive picture of hydrographic conditions both before and after plant startup in 1975. The seasonal variability of the inner and the outer harbor waters has received particular emphasis, and the hydrographic impacts of plant operation are reviewed in detail.

Study Area

New Haven Harbor is a shallow embayment located on the northern shore of Long Island Sound slightly east of its midpoint, roughly halfway between New York City and Providence, Rhode Island. It is one of the largest harbors on Long Island Sound. Hydrographically, New Haven Harbor is an estuary as defined by Pritchard (1967). Circulation and mixing patterns, which dominate almost all other aspects of estuarine behavior, are difficult to measure and analyze because they are cumulative results of tides, freshwater flow, irregularities in the estuarine configuration, and density differences between fresh and salt water (National Academy of Sciences, 1977).

New Haven Harbor is largely surrounded by urbanized land. The intensity of this urbanization and associated industrialization has brought with it all the attendant problems of municipal and industrial pollution ranging from sewage to oil spills.

At present, effluent from three primary sewage treatment plants flows into New Haven Harbor. The East Street and Boulevard plants discharge at their shoreline locations on the west side of the harbor; the East Shore plant empties its wastes through a shallow subaqueous discharge south of the New Haven Harbor Station; their combined volume is on the order of $4.4 \text{ m}^3/\text{sec}$ (100 million gal/day or $156 \text{ ft}^3/\text{sec}$). In addition, the West Haven facility (secondary treatment) near Sandy Point empties into the main channel area east of Sandy Point via a subsurface discharge.

Several inland communities discharge their municipal wastes into the Quinnipiac River, although all now have secondary sewage treatment facilities. According to the Connecticut Department of Environmental Protection (1977), the waters of New Haven Harbor are at present classified as follows: inner harbor, SD (unacceptable); outer harbor, SD and SC (unsuitable for bathing); and adjacent Sound beyond the breakwaters, SB (suitable for bathing).

General Hydrography of New Haven Harbor

To delineate the harbor area for purposes of this study, three breakwaters are considered to bound the harbor on the Sound side and locations in the three rivers, Quinnipiac, Mill, and West, are used as boundaries at the head of the harbor (Figure 1-1). For the purpose of this report, the harbor is divided into two parts by a line between Sandy Point and Fort Hale Point which separates it into inner and outer portions. These boundaries were also used by Duxbury (1963).

The bottom of the outer harbor is sandy with large areas of shell reefs and some exposed bedrock, while the inner harbor bottom is composed chiefly of fine-grained sediments with a high organic content.

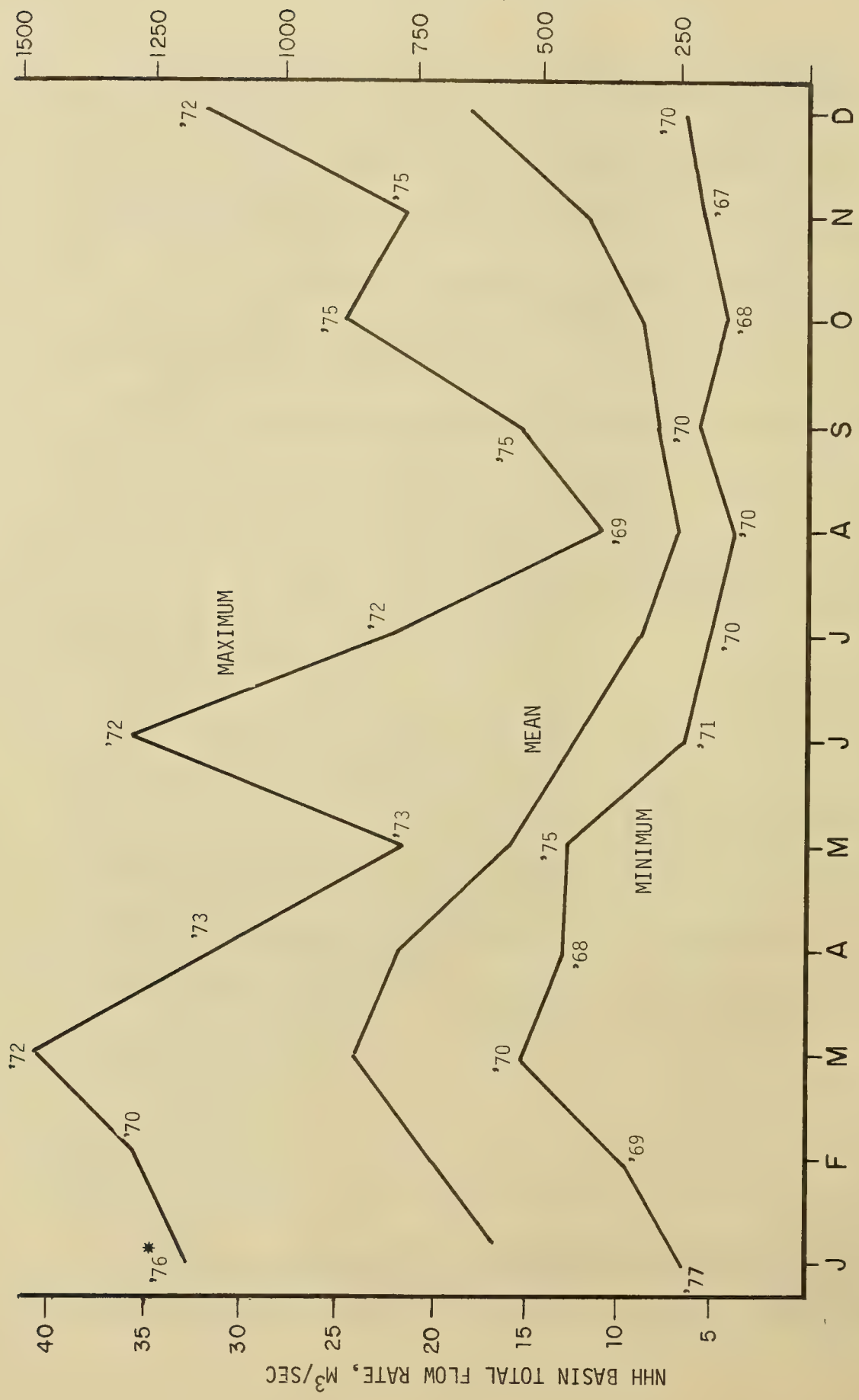
According to Duxbury (1963), the total area of the harbor within the arbitrarily chosen limits is approximately 18.4 km^2 , with 4.2

km² of this area representing the inner harbor and 14.1 km² the outer harbor (areas determined from mean low water (MLW) datum contour on NOAA-NOS Chart No. 218). Mean depths below MLW are 3.5 m for the total harbor with 2.7 m and 3.7 m for the inner and outer harbors, respectively. Since the mean tidal range for New Haven Harbor is approximately 1.9 m (NOAA-NOS, 1977), the tidal prism is approximately $5.3 \times 10^7 \text{ m}^3$. This prism represents a conservative estimate of the mean volume of water that must flood into and ebb out of the harbor during a complete tidal cycle. The entrance to the harbor is formed by a dredged channel, the depth of which decreases from approximately 10.4 m at the breakwater entrance to 4.9 m at the Ferry Street Bridge in the Quinnipiac River (Figure 1-1).

Hydrology of the New Haven Harbor Drainage Basin

The Quinnipiac, Mill and West Rivers drain a total of 624 km² (241 mi²) of south central Connecticut, with the Quinnipiac contributing about 80% of the total flow. Normal precipitation and runoff data from U.S. Geological Survey records (USGS, 1969 to 1976) show little monthly variation over a well-documented annual cycle (Long Island Sound Regional Study, 1963). This annual cycle of estimated total monthly runoff^{*} for 1967 to 1977 shows peak values in March (mean of 24.2 m³/sec), a gradual decrease through the spring and early summer to a low of 7.1 m³/sec in August, and then a gradual increase through the fall and winter culminating with the March peak (Figure 3-1). This annual cycle plays a major role in the patterns of harbor circulation.

* Assuming uniform rainfall over the entire 624 km² area, runoff data from the gauged portions of the drainage basin were used to estimate runoff from the ungauged portions and compute an approximate monthly total.



* Number ('76) indicates year of maximum or minimum.

Figure 3-1. Estimated mean monthly runoff, 1967-1977. New Haven Harbor Ecological Studies Summary Report, 1979.

General Patterns of Circulation in Long Island Sound

The waters of New Haven Harbor ultimately flush into Long Island Sound, which covers more than 2400 km² and whose circulation patterns have been well characterized by the Long Island Sound Regional Study (1973). The following is a brief summary from that report.

Circulation patterns in Long Island Sound and adjacent estuaries are controlled by tides, fresh water inflow, winds and other weather conditions, bottom topography and salinity and temperature gradients. The circulation pattern influences the chemical composition of the water and the sediment distribution within the basin. In general, the tidal range increases to the west, while current velocities decrease. The circulation pattern in the Long Island tidal basin shows an exchange of water at the eastern end with a net outward flow of surface water to Block Island Sound and an influx of more dense bottom water from Block Island Sound. In western Long Island Sound, surface fresh water moves eastward into the Sound from the East River, while Sound bottom water flows westward into the East River. In central Long Island Sound, the tidal current patterns flow in an elliptical counterclockwise direction. Upwelling occurs in the central Sound, resulting in decreased transport in bottom layers. Upwelling has been reported along the Connecticut shore between New Haven and Old Saybrook and in coastal Long Island between Mattituck Inlet and Orient Point (Hollman and Sandberg, 1972 in Long Island Sound Regional Study, 1973). Tidal currents run parallel to the shoreline under the influence of coastal topography.

Climatology

The Long Island Sound climate has also been described in some detail in the Long Island Sound Regional Study (1973). The four seasons, consistent monthly precipitation, localized temperature changes, and the moderating maritime influence of Long Island Sound air masses

characterize the climate of this area. The moderating maritime influence is most evident in late spring and summer, when water temperatures are cooler than air temperatures, and in the late autumn and winter, when water temperatures are generally warmer than air temperatures. The climate is spatially and annually variable. Mean annual temperatures range from 9.4 to 12.8°C decreasing eastward from New York City, inland from the Connecticut coastline, and eastward on Long Island (Long Island Sound Regional Study, 1973). Monthly means of daily maximum and daily minimum air temperature from 1971 to 1977 at Bridgeport, Connecticut, show a regular pattern (Figure 3-2). Warmest temperatures generally occurred in July, but during 1973 and 1976 peak temperatures occurred in August; highest summer mean was in July 1974 (29.2 C) whereas the lowest was in July 1971 and August 1976 (18.3 C). Coldest temperatures occurred in January or February with record cold occurring in January 1977, when the mean minimum was -8.1 C and the mean maximum -1.4 C.

Monthly totals of daily precipitation at Bridgeport from 1971 to 1977 are presented in Figure 3-2.

Previous Studies - New Haven Harbor

The harbor has been actively studied from a number of viewpoints over the years. The New Haven Harbor Station Ecological Monitoring Studies by Normandeau Associates, Inc. (NAI) provide the most recent and comprehensive information on hydrographic characteristics of the harbor waters. Beginning in May 1971, monthly hydrographic surveys (up to 20 harbor-wide sampling stations and continuous *in situ* monitoring) have measured the following parameters: temperature, salinity, dissolved oxygen, pH, and turbidity (NAI, 1971b, 1972, 1973a, 1974a, 1974b, 1975a, 1976a, 1977a and 1978a). On September 3, 1975, a series of thermal infra-red overflights was conducted to document the New Haven Harbor thermal regime during operation of the New Haven Harbor Station (NAI, 1976b); extensive *in situ* information on ambient water temperatures was also collected during these overflights. During the summer and fall

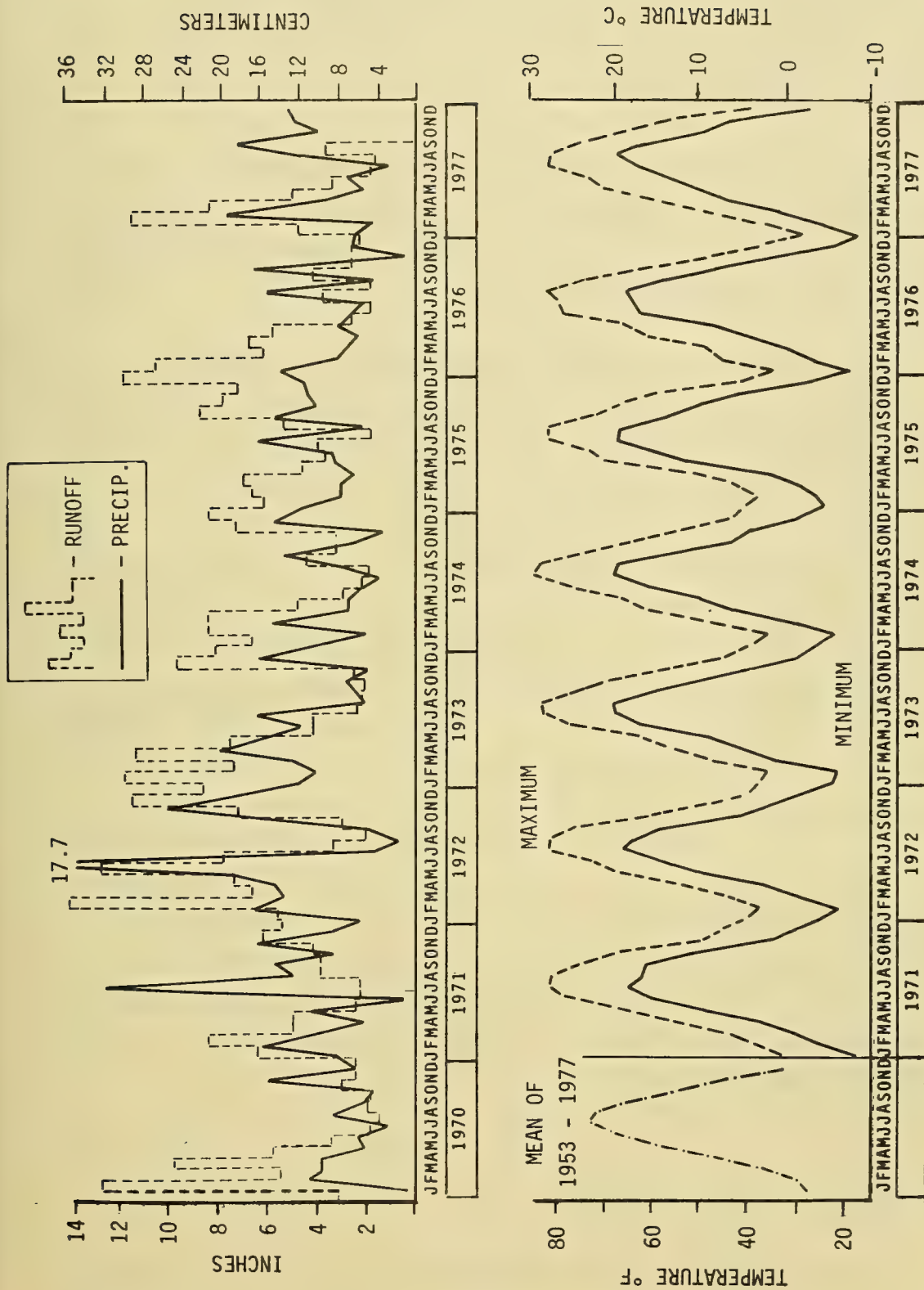


Figure 3-2. Monthly precipitation and monthly means of daily temperature maxima and minima in Bridgeport, Connecticut area, with predicted runoff for New Haven Harbor watershed. New Haven Harbor Ecological Studies Summary Report, 1979.

of 1976, a series of three-dimensional thermal surveys and continuous releases of Rhodamine WT dye were conducted to distinguish the thermal load introduced by the New Haven Harbor Station from other natural and man-made thermal influences (NAI, 1977b).

A mathematical model developed in 1971 by EBASCO was used to evaluate possible discharge configurations. Physical model studies by the University of Florida were used to evaluate a buoyant jet configuration for the plant discharge (UOF, 1972).

Limited drogue studies and current-meter measurements have helped to confirm historical data on circulation patterns in the estuary relative to dispersal of sewage effluents (NAI, 1975b; Goodkind & O'Day and Fay, Spofford and Thorndike, 1970a and b; and Quirk, Lawler and Matusky Engineers, 1969). Other data sources include hydrographic surveys and a hydrodynamic mathematical model being developed for New Haven sewage treatment plant siting (NAI, in preparation). Additional data have been reported in earlier Raytheon ecological studies of the harbor (1970a, 1970b, 1971), Duxbury's studies of general circulation patterns in the harbor (1963), and in government documents on the harbor shellfish resource and water quality (FWQA, 1970) and maintenance of dredging activities (U.S. Army Corps of Engineers, 1973b).

Various studies of UI's English Station, located in the upper estuary on the Mill River about 2.6 km north of the New Haven Harbor Station, have focused on turbine heat specifications (UI, 1970), the effect of heated cooling water discharges on Harbor temperatures (EBASCO, 1971a and b and NAI, 1971a, 1974c and 1974e), and thermal surveys of the receiving waters adjacent to the plant.

Previous Studies - Long Island Sound

A fairly broad data base is available for the waters of Long Island Sound. A report on the water quality of Long Island Sound was

prepared by the Federal Water Supply and Pollution Control Administration (1969) and U.S. Environmental Protection Agency (1971). Basic hydrographic studies of the Sound were conducted by Riley and Conover (1956), and Riley (1956 and 1959). Reports were compiled on the movement and quality of Long Island Sound waters (Hardy and Weyl, 1970; Hardy, 1972a and b), distribution of dissolved oxygen in Long Island Sound (Hardy and Weyl, 1971), sources and movements of water in the Sound (Long Island Sound Regional Study, 1973 and 1975), physical oceanography and water quality of western Long Island Sound (Jay and Bowman, 1975), gravitational circulation in Long Island Sound (Wilson, 1976), and environmental baseline studies in the Sound from 1972 to 1975 by the National Marine Fisheries Service (Reid, Frame and Drexler, 1976). A temperature prediction model for Long Island Sound was prepared by Stone and Webster (1972). More recently, Bowman has prepared a pollution prediction model of Long Island Sound (1976) and examined nutrient distribution and transport in the Sound (1977). Garvine and Monk have studied the frontal structure of the Connecticut River plume (1974), and Gordon (1973) and Bokuniewicz (1974, 1975 and 1976) have published a number of reports on sedimentation and dredging activities in Long Island Sound.

Environmental Studies at Other Power Plant Sites

In addition, certain environmental data from various other operating power plants on Long Island Sound are available for purposes of comparison with possible impacts at New Haven Harbor Station. These include: thermal surveys and hydrographic studies at Bridgeport, Connecticut (NAI, 1973b); biological studies at Stamford, Connecticut (NAI, 1974d); thermal plume studies at Middletown, Montville, Norwalk and Devon Stations (Lawler, Matusky and Skelly Engineers, 1975a, b and c; 1976); hydrographic studies at Millstone Nuclear Station (Battelle, 1977); biological and hydrographic studies of thermal pollution at Northport, New York (SUNY Marine Sciences Research Center, 1970; Weyl, 1971); and baseline studies at Shoreham Station, New York (New York Ocean

Science Laboratory, 1974). Local climatological data to supplement these studies are available from various National Weather Bureau Stations including both New Haven (through 1969) and Bridgeport (through 1977), Connecticut.

METHODS

Physical and chemical measurements were taken monthly in New Haven Harbor and adjacent Long Island Sound from May 1971 through October 1977. Station locations are shown in Figure 3-3. Results of these monthly surveys provide a comparison with data collected at the continuous monitoring station located on the New Haven Harbor Station pier.

Monthly Surveys

Profile measurements of temperature, conductivity, dissolved oxygen, pH, and transparency were obtained during monthly surveys at 17 sampling stations (Figure 3-3) at both high and low tides. Measurements were made at 1-m depth intervals from surface to bottom. Temperature, conductivity, dissolved oxygen, and pH values were measured in the field using a Hydrolab Surveyor Model 6D water quality analyzer. Transparency was measured with a Secchi disc. On each given survey date, data were collected during 3-hr periods within 1.5 hrs of high-water slack (data designated as "flood") and low-water slack (data designated as "ebb"). Salinity values were calculated from conductivity observations.

Prior to each monthly survey, the Hydrolab Surveyor system was calibrated in accordance with procedures recommended by the manufacturer, as modified by NAI for the purposes of this study. Calibration of the system was checked after each survey to permit evaluation of the acceptability of data. All data were accepted.

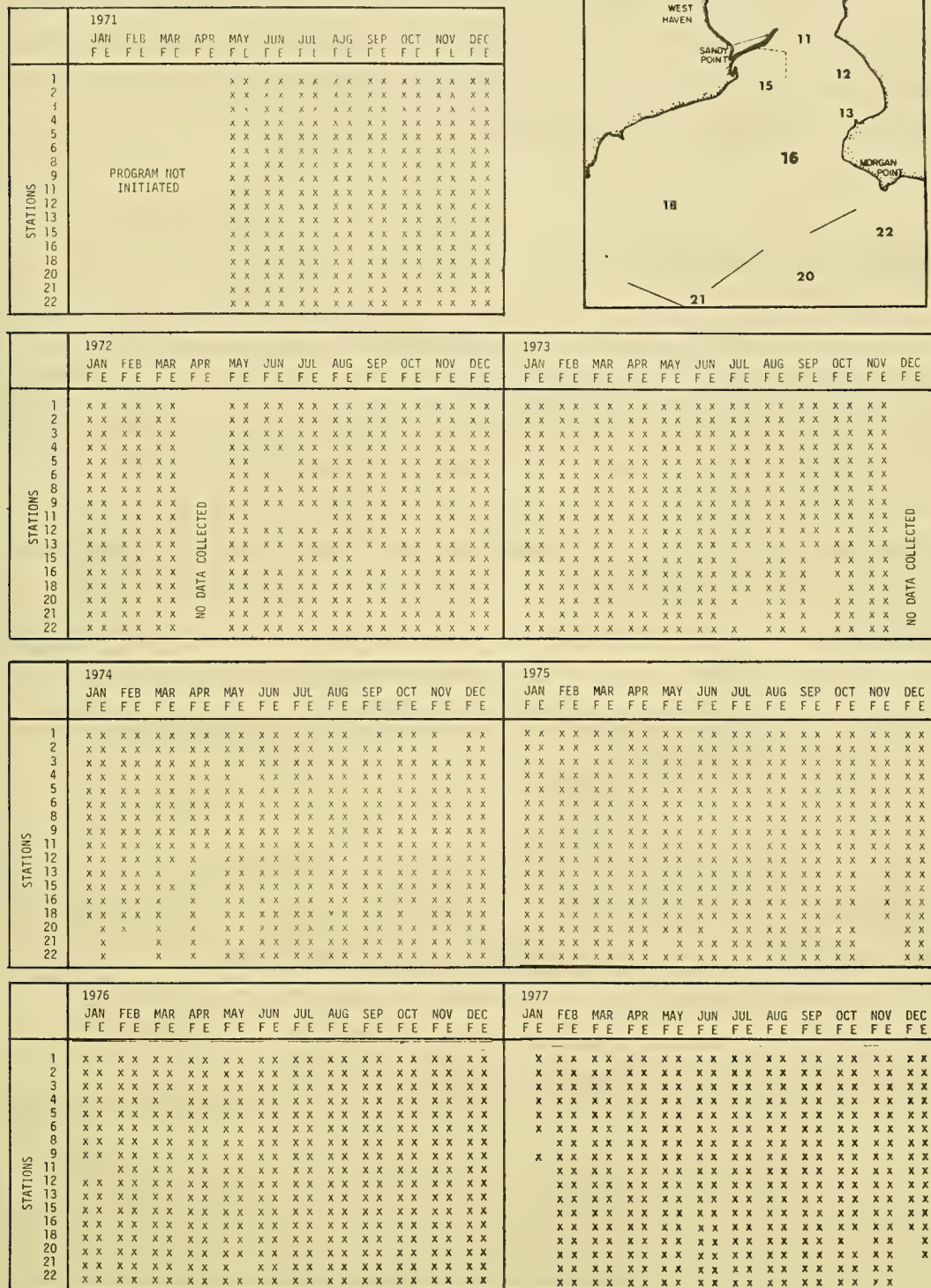


Figure 3-3. Physical/Chemical data collected from May 1971 to October 1977. New Haven Harbor Station Ecological Monitoring Studies, 1979.

In addition to routine survey and post-survey calibrations, beginning in July 1976 water samples were collected at Stations 2, 9 and 20 at surface and near bottom on each ebb-tide survey for independent determination of salinity (by laboratory salinometer) and dissolved oxygen (by Winkler titration). These independent estimates were used as a check on accuracy of the Hydrolab Surveyor.

Continuous Monitoring Station

A Honeywell continuous water quality monitoring station has been in operation on the New Haven Harbor Station pier since August 1970. Water is pumped to the sensing instrument package from a depth of 12 ft below mean sea level (MSL); reported data refer to this depth unless otherwise indicated. Except for gaps due to maintenance and malfunctions, data have been recorded continuously at 6-min intervals for the following parameters:

Time	Temperature (at surface and -12 ft
pH	MSL)
Conductivity	Tide height (diaphragm positioned at
Turbidity	-12 ft MSL)
Dissolved Oxygen	

Accuracy of the various sensors was checked weekly against alternative instruments or chemical analysis (dissolved oxygen) and appropriate adjustments were made to the Honeywell unit accordingly.

DESCRIPTION OF NEW HAVEN HARBOR HYDROGRAPHY

In general, our surveys have shown that New Haven Harbor experiences typical seasonal patterns in physical/chemical parameters: 1) warmest water temperatures are reached in July and August, while coldest temperatures occur in January and February; 2) lowest salinities

occur during periods of winter thaw (February, March) and spring runoff (April and May); and 3) dissolved oxygen levels are inversely related to seasonal temperature fluctuations. Transparency and pH show little evidence of seasonal variation.

Description of the hydrography of New Haven Harbor necessitates the detailed presentation of data which characterize spatial and temporal differences and similarities in the parameters measured. To facilitate these comparisons, actual data, rather than statistical constructs (means, standard deviations, etc.) are presented. The final year of data collection, November 1976-October 1977, was arbitrarily selected as a "sample year" for detailed examination of spatial and seasonal trends. This sample year description was then utilized as a basis for multi-year comparisons. This approach reduces the redundancy attendant with presentation of all data years in detail and avoids the artificiality of combinative statistics. Means of observations distributed among many years may not represent either characteristic or actual occurrences, and thus require more critical review than actual values.

Our characterization of the hydrography of New Haven Harbor consists of a general description of circulation patterns and the estuarine nature of the harbor, a detailed description of a sample year by month, a discussion of characteristic spatial variability within the harbor, a description of similarities and differences between the sample year and other years studied, and a summary of the hydrography of New Haven Harbor.

Estuarine Classification and Harbor-Wide Circulation Patterns

The major estuaries in the Long Island Sound region are the Connecticut, Thames, Housatonic and Quinnipiac (NERBC, 1973). In general, there is a two-layer transport system at the heads of these estuaries. Fresh water flows seaward near the surface while the tides move

denser saline water upstream along the river bottom. Salinity generally increases downstream and from top to bottom at any point in the brackish part of the estuary. The distribution of salinity changes with the tidal stage and the amount of fresh water inflow.

Though various attempts have been made to classify estuaries into types (Officer, 1977), such typifications must remain somewhat imprecise, as there is a continuous range in nature of such characteristics as geometry, bathymetric configuration, and physical characteristics of circulation and mixing. Furthermore, estuaries are by definition the interface of river and sea, making them extremely dynamic and changeable. Nevertheless, despite the inherent problems, a distinction can be made in terms of the vertical salinity distribution. Estuaries can range from a "well-mixed" condition in which there is essentially no variation in the salinity in a vertical column, to a "stratified" condition with a halocline between the upper and lower portions of a water column. In New Haven Harbor, conditions range from unstratified to weakly or partially stratified (salinity change of a few parts per thousand (ppt) from surface to bottom) to a "strongly or highly stratified" situation (salinity change of at least 5 to 10 ppt from surface to bottom).

The driving forces for estuarine circulation are longitudinal surface slope (acting in a "down estuary" direction) and the longitudinal density gradient force which is a function of ambient salinity and temperature (acting in an "up estuary" direction). These two driving forces are balanced by the internal and bottom frictional forces. For the condition in which the river runoff is small, as in New Haven, the net effect is that the surface slope force will be dominant in the upper portion of the water column, producing a seaward flow, and that the density gradient force will be dominant in the lower portion of the water column, producing a landward flow. In some cases there can be an important contribution from a third driving force, wind stress at the surface, and in fact wind effects are often important in New Haven Harbor circulation.

General circulation patterns in New Haven Harbor have been documented by Duxbury (1963). His composite chart for flood-tidal currents (Figure 3-4) shows an indraft from Long Island Sound at speeds varying from 22 to 45 cm/sec flowing northward along the channel axis and upward into the Quinnipiac at 27 cm/sec. Apparently the flow into Morris Cove is not as strong during the flood as during the ebb, suggesting that residual inner harbor waters from the preceding ebb tide are not entirely displaced by the flood. During the ebbing tide, a small eddy forms between Long Wharf and the West River channel, causing a localized trapping of water and a consequent decrease in flushing rate (Figure 3-4). The velocity shear between this eddy and the flow out of the main channel creates a line of floating debris (personal observation). Also, there is a tendency for the ebb to flow into Morris Cove at a relatively high rate near shore (27 cm/sec) causing debris from the inner harbor to be carried close to the shore at both Fort Hale and Lighthouse Points. Flow observations at the mouth of the Mill and Quinnipiac Rivers show ebb trapping of Mill River effluent along the western bank and eventual contribution to the eddy off Long Wharf. On the flooding tide, water from the inner harbor is carried upstream into both rivers.

Data collected by NOAA-NOS at the harbor entrance show a mean maximum current velocity of 21 cm/sec on flood tide and 31 cm/sec on the ebb. At the Tomlinson Bridge, mean peak tidal current velocity is 21 cm/sec on flood and 26 cm/sec on ebb. Tidal flow rates vary according to the stage of the tide but average about $2500 \text{ m}^3/\text{sec}$ over an entire 12.4-hr tidal cycle. Ebbing tidal currents are stronger than those on flood (Duxbury, 1963) due to the net seaward transport of freshwater runoff. Stronger currents are generally restricted to the main harbor channel, except for fairly strong (37 to 67 cm/sec) currents to the south of Morris Cove and directly off Lighthouse Point during ebb tide. In the main channel inside the breakwaters, the average current is only 21 cm/sec.

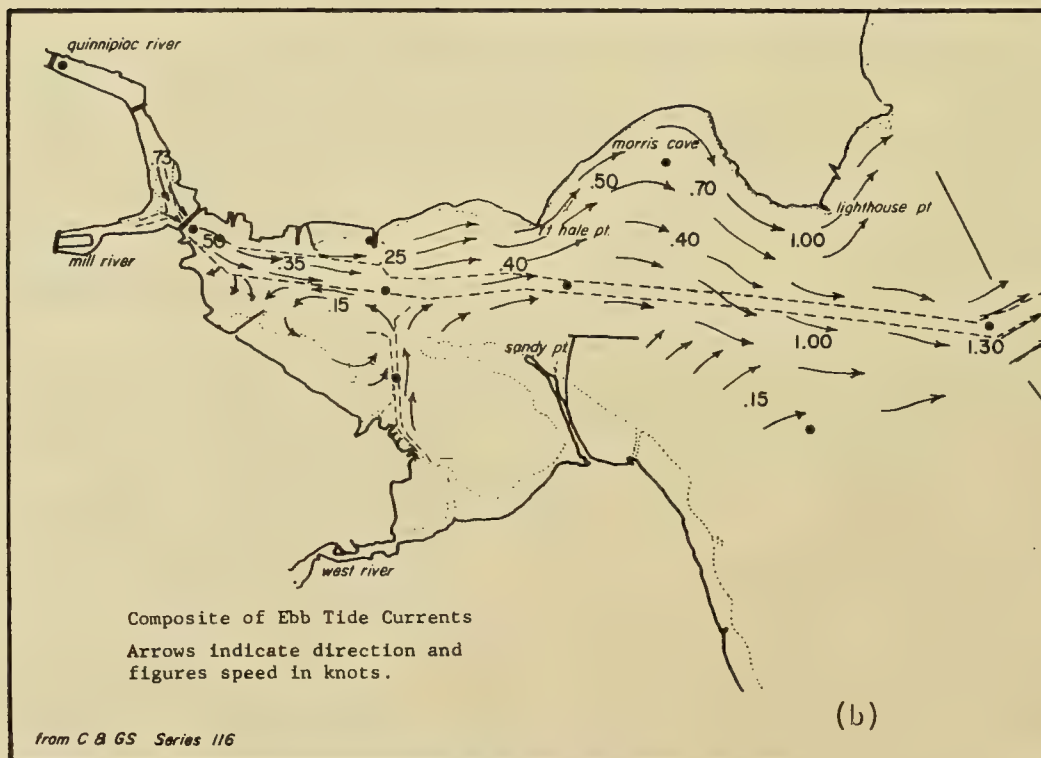
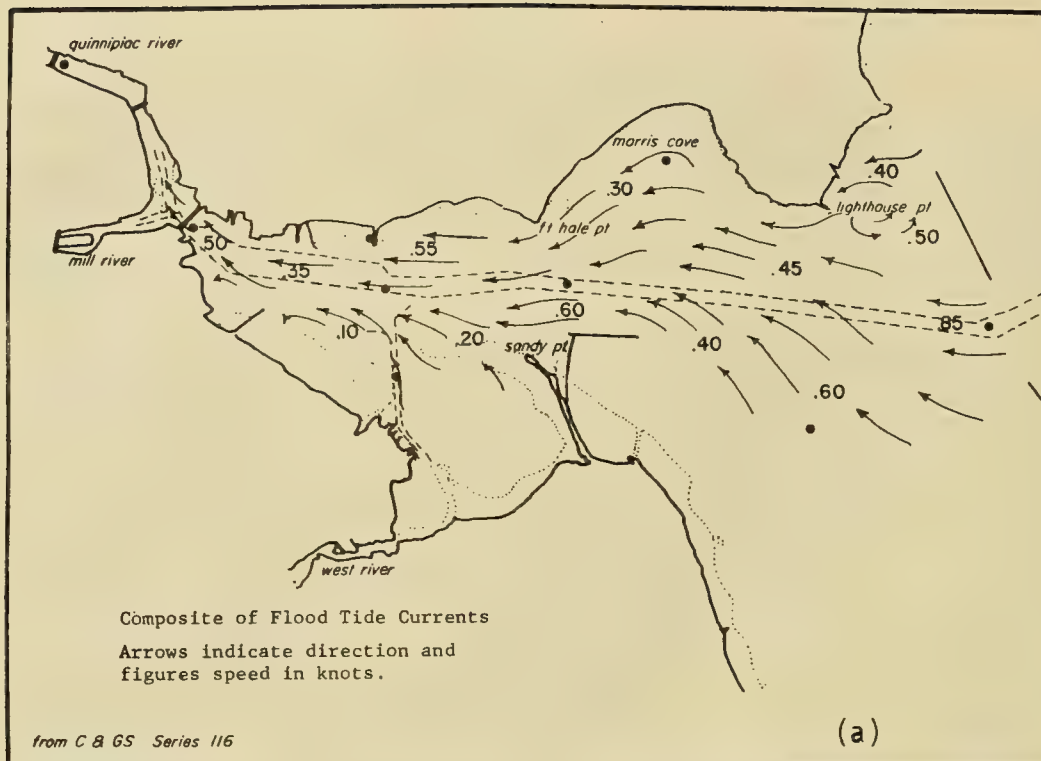


Figure 3-4. Composite flood (a) and ebb (b) tide currents, New Haven Harbor (From Duxbury, 1963). New Haven Harbor Ecological Studies Summary Report, 1979.

Data from thermal infrared overflights, aerial photographs of sewage effluent plumes, and drogue studies in the inner harbor confirm the basic circulation pattern described by Duxbury.

Salinity Distribution

The physical/chemical water column measurement program for the New Haven Harbor Station Ecological Studies has focused on ambient salinity and temperature distributions. Review of the data from monthly hydrographic surveys since May 1971, continuous measurements from the Honeywell Water Quality Monitor (operating at the New Haven Harbor Station pier since August 1970), plant intake measurements by UI personnel, and special surveys and supplemental data from other workers in the harbor show that the degree of stratification varies sharply from the head of the estuary (moderately stratified) to the mouth of the estuary (weakly stratified or well mixed).

In general, New Haven Harbor's salinity fluctuations reflect relative changes of rates of evaporation and precipitation (runoff). As a result of high evaporation and low freshwater runoff, maximum salinity values are observed from June to September; lowest values occur during February, March and April when freshwater runoff is at a peak. Warmer, less saline water tends to flow out over cooler, more saline (and consequently, denser) ocean water. Ebb-tide salinity values are lower than flood-tide values at inner harbor stations during periods of significant runoff. Mean salinity over the course of the sample year was 20.9 ppt and ranged from 2.0 to 27.7 ppt.

Data from the sample year (November 1976 through October 1977) show the details of annual salinity variations in the Harbor (Figures 3-5, 3-6). During November sampling, Long Island Sound waters along the axis of the main channel near the harbor mouth ranged from 27 ppt on the surface to 28 ppt on the bottom. On the flooding tide, strong landward flows created a sharp gradient between Stations 8 and 11 and carried

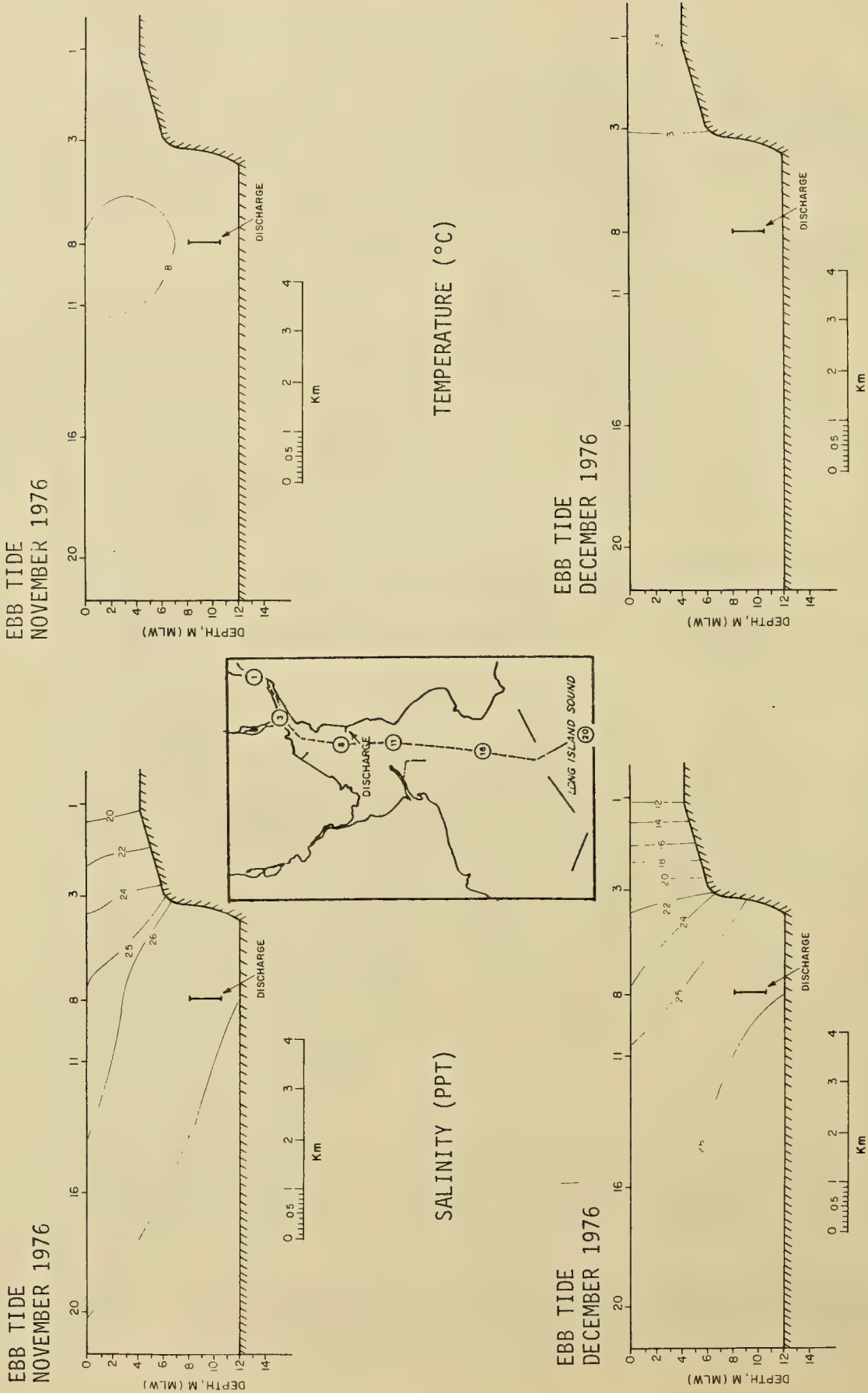
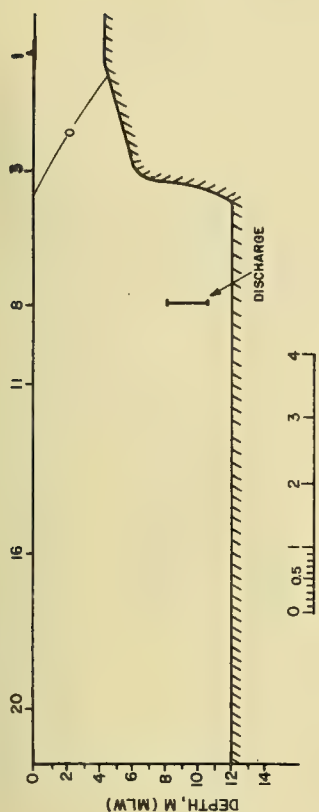


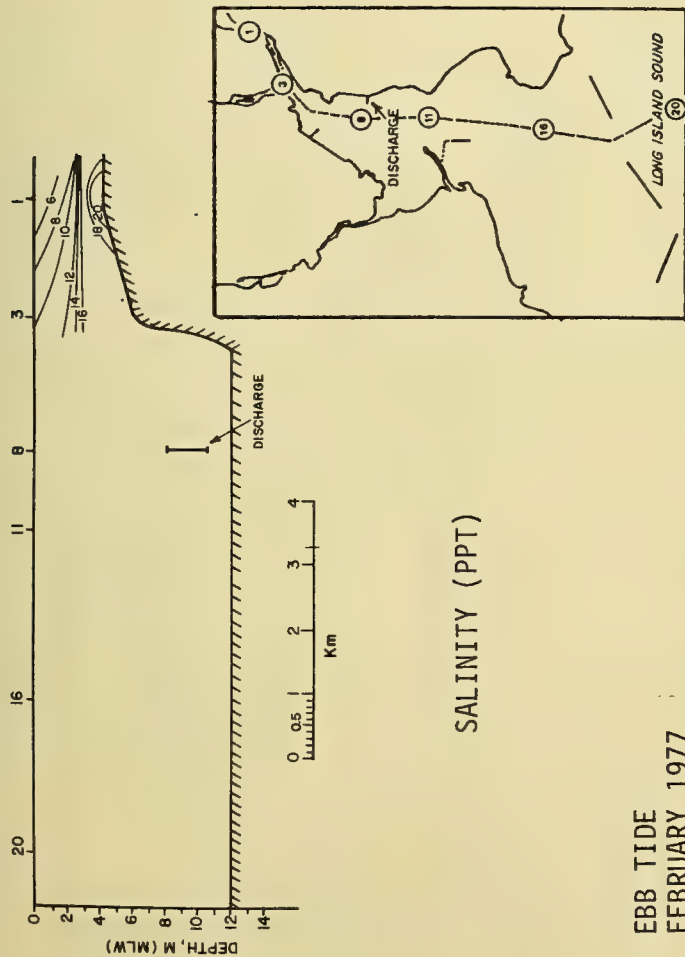
Figure 3-5. Salinity and temperature transects along the axis of the New Haven Harbor channel, ebb tide, November 1976-October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

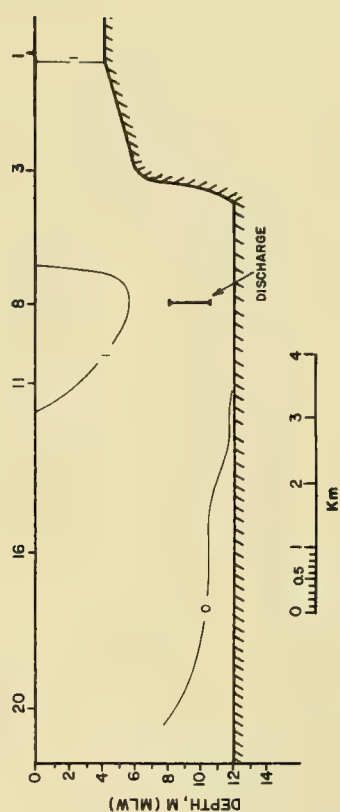
EBB TIDE
JANUARY 1977



EBB TIDE
JANUARY 1977



EBB TIDE
FEBRUARY 1977



EBB TIDE
FEBRUARY 1977

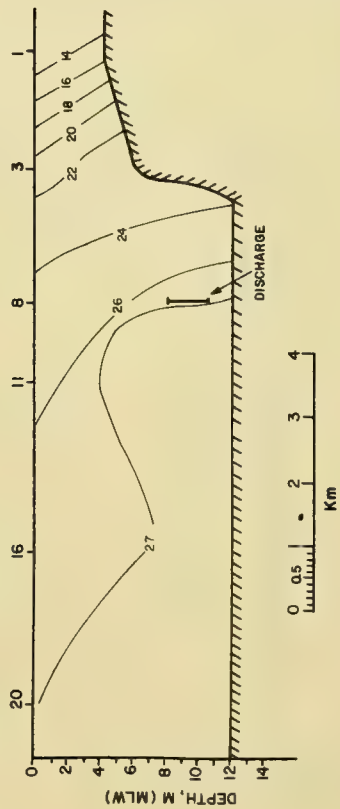
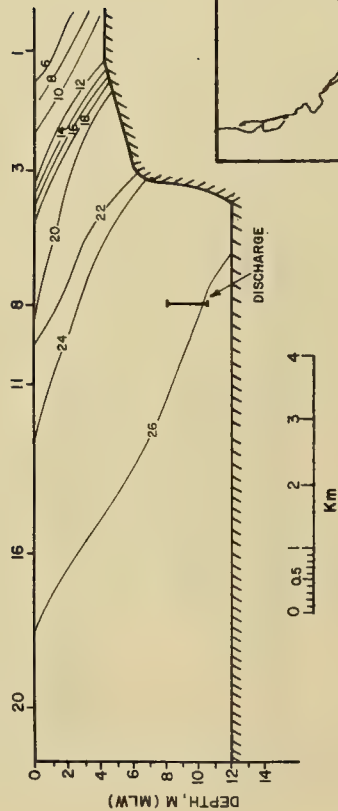


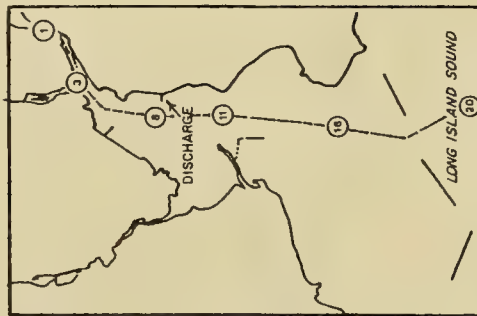
Figure 3-5. (Continued)

Continued

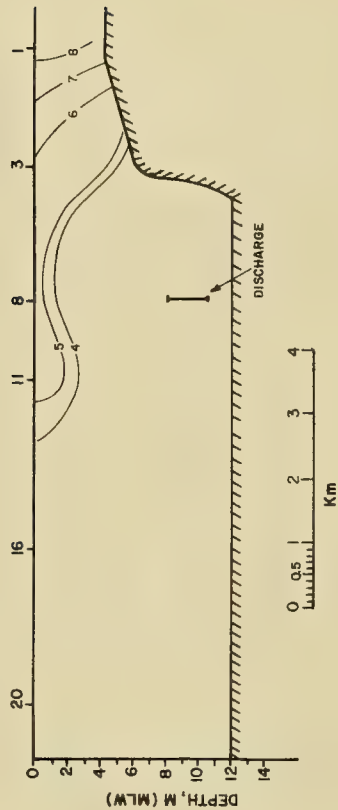
EBB TIDE
MARCH 1977



SALINITY (PPT)

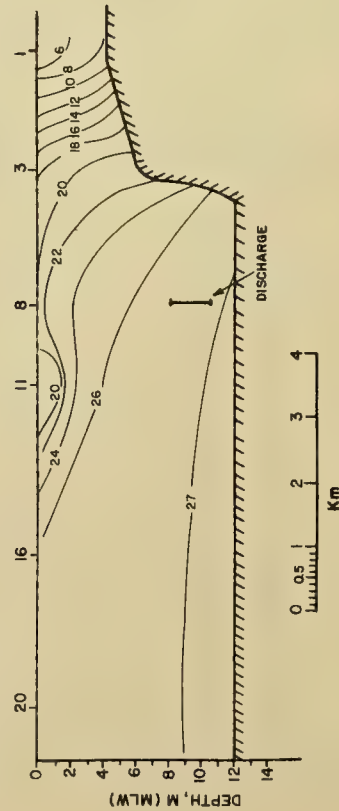


EBB TIDE
MARCH 1977



TEMPERATURE (°C)

EBB TIDE
APRIL 1977



EBB TIDE
APRIL 1977

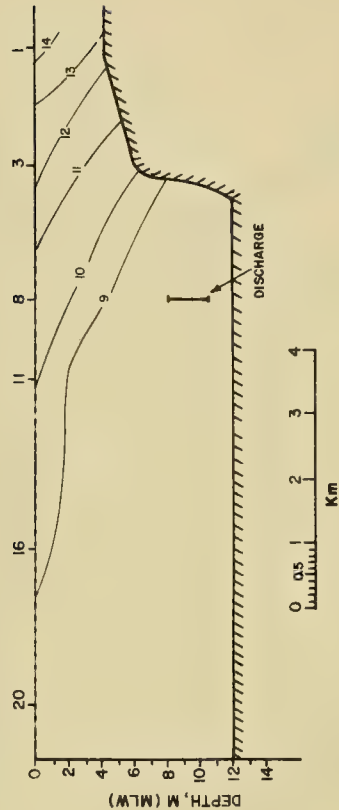
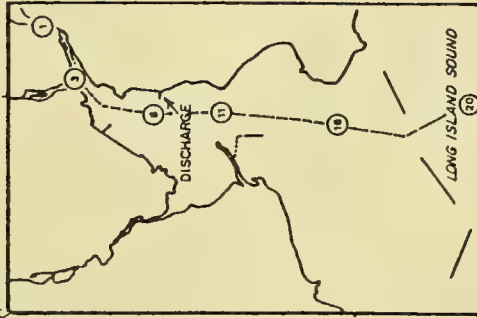
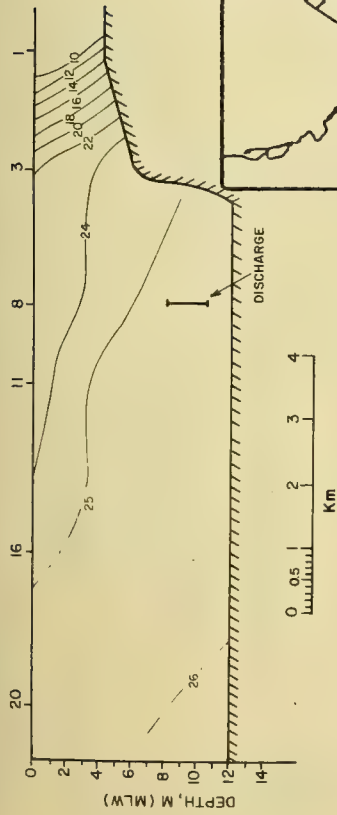


Figure 3-5. (Continued)

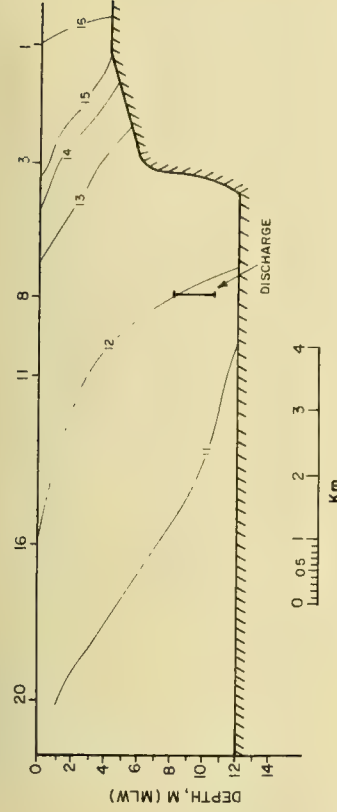
Continued

EBB TIDE
MAY 1977

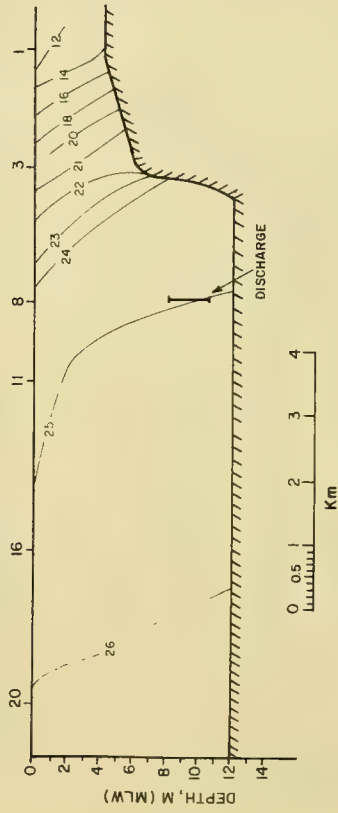


SALINITY (PPT)

TEMPERATURE ($^{\circ}\text{C}$)



EBB TIDE
JUNE 1977



EBB TIDE
JUNE 1977

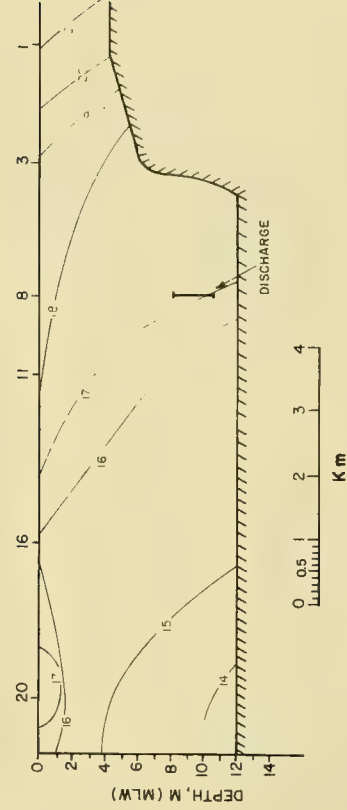
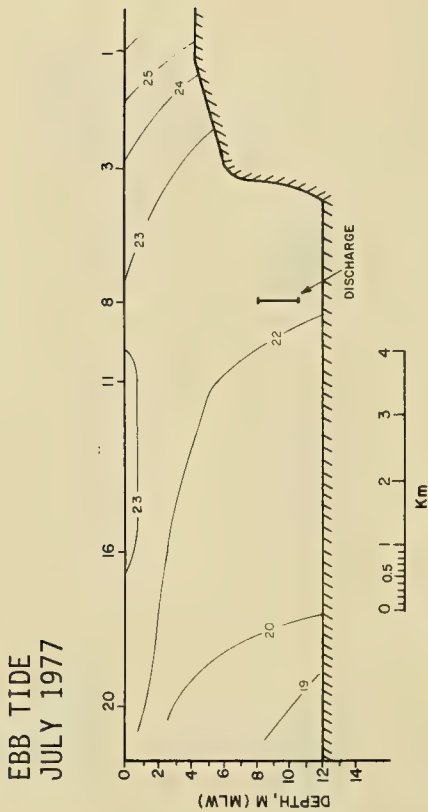
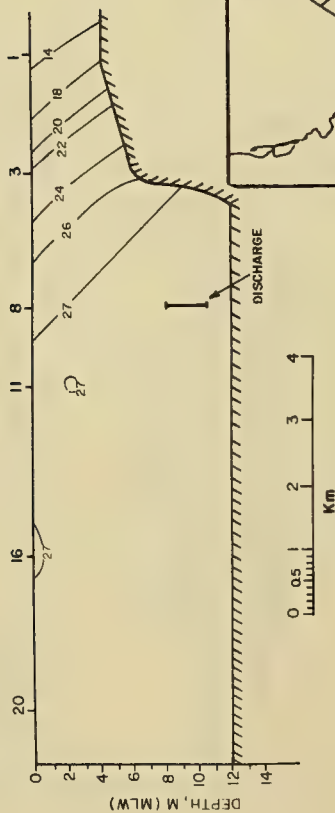


Figure 3-5. (Continued)

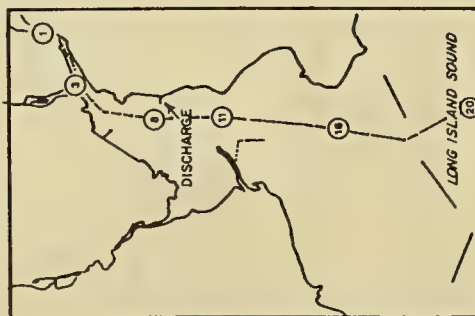
Continued

EBB TIDE
JULY 1977

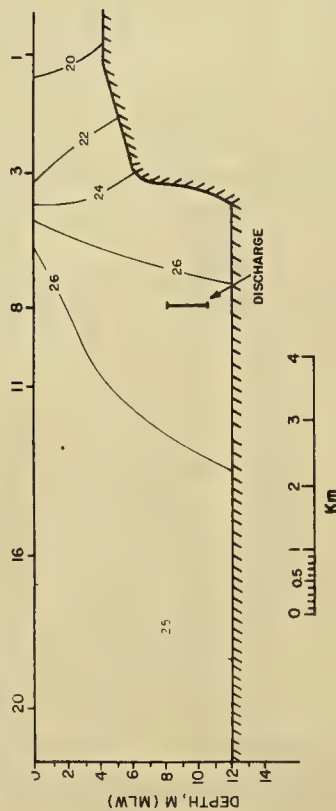


SALINITY (PPT)

TEMPERATURE (°C)



EBB TIDE
AUGUST 1977



EBB TIDE
AUGUST 1977

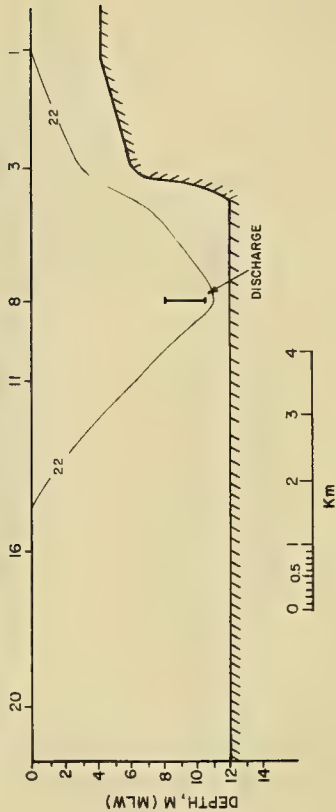
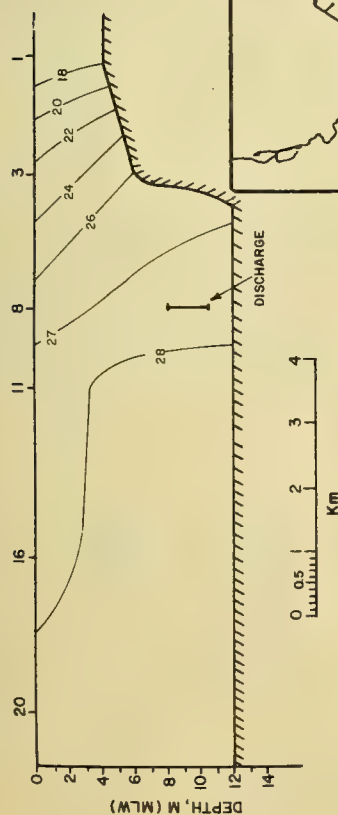


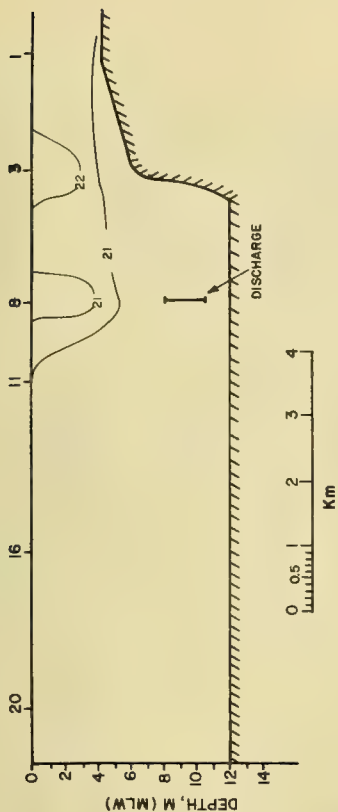
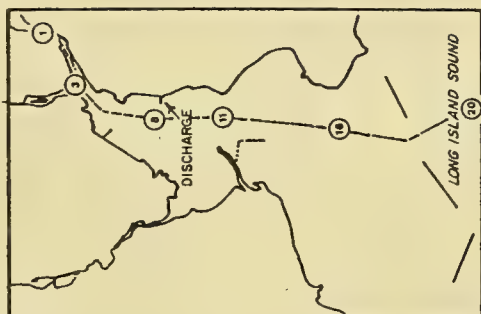
Figure 3-5. (Continued)

Continued

EBB TIDE
SEPTEMBER 1977

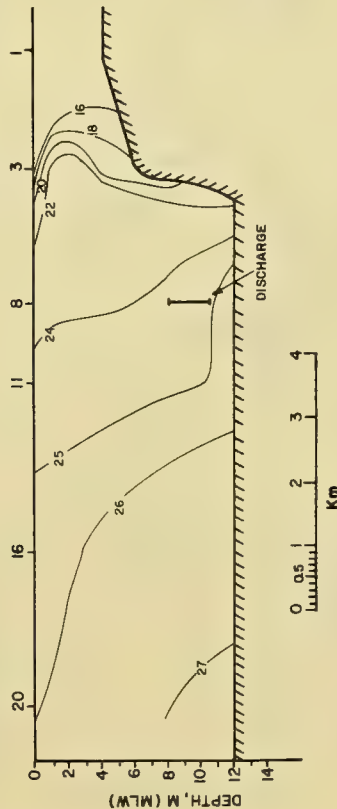


SALINITY (PPT)



TEMPERATURE (°C)

EBB TIDE
OCTOBER 1977



EBB TIDE
OCTOBER 1977

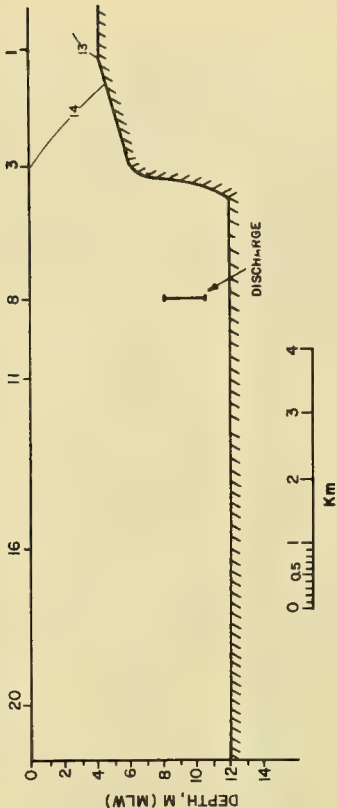


Figure 3-5. (Continued)



Figure 3-6. (Continued)

residual ebb-tidal waters from the preceding tide (24.1 to 26 ppt) northward into the upper estuary. On the ebbing tide, salinities near the head of the estuary decreased to 19 to 25 ppt and relatively fresh waters were carried southward beyond Fort Hale Park. At the harbor mouth, salinities were essentially unchanged through both phases of the tide. In December, salinity at the harbor mouth was down slightly, to 26 ppt at the surface and 27 ppt near the bottom. Flood-tidal salinities throughout the estuary were 1 to 2 ppt lower than in November, whereas on the ebbing tide values at the head of the estuary were down to 12.7 ppt. Due to severe weather conditions during January, only ebb tide inner harbor measurements were made. Data showed that, on the ebbing tide, pronounced freshening was apparent at the head of the estuary (down to 6 ppt). February conditions were very similar to those observed during December. Flood-tidal surface salinity values also showed freshened discharge from the West River extending out beyond Sandy Point and slightly more saline conditions on the east side of the harbor.

By March, the influence of peak annual runoff caused a marked decrease in salinities. During flood tide, salinities at the harbor mouth were 26 ppt, at both the surface and bottom. The inner harbor showed pronounced near-surface stratification; salinity ranged from 12 to 19 ppt. On the ebbing tide, salinities near the head of the estuary decreased to 6 ppt and strong stratification was evident out beyond Station 11. The remainder of the outer harbor actually had higher salinities. In April, the same basic pattern was repeated, with pronounced salinity stratification in the inner harbor and slightly higher salinities in the outer harbor on the ebbing tide.

In May, salinities reached the lowest values of the year, probably due to a lag of the salinity minima of Long Island Sound waters behind the annual peak in runoff. Flood-tidal salinities were about 25 ppt at the harbor mouth, slightly lower in the inner harbor, and strongly stratified near the head (down to 12 ppt). As during the preceding months, ebb tidal salinities in the outer harbor showed a slight in-

crease over flood (about 1 ppt overall) and strong stratification at Station 1 (8.7 ppt at the surface and 11.2 ppt at the bottom). The salinity contour maps for May showed more saline conditions along the main channel and the eastern portion of the harbor, with less saline waters in the western portion of the harbor. In June, salinities started to increase again. Long Island Sound waters at the harbor mouth were vertically homogeneous, averaging around 26.6 ppt. Flood-tidal stratification was fairly weak (down to 17.9 ppt on the surface at Station 3). During ebb tide, the mid-channel waters showed very little change, whereas, near the head of the harbor, surface salinities were down to 11.9 ppt and some stratification was apparent. July salinities rose slightly, to 27.7 ppt at Station 1. Both flood and ebb waters near the head of the estuary showed patterns identical to those of June, but with salinities 1 to 2 ppt higher.

During August, when runoff typically reaches its yearly minimum, Long Island Sound waters ranged from 24.8 to 27.0 ppt. The outer harbor was quite homogeneous, whereas the inner harbor and the head of the estuary were considerably more saline than earlier in the year (18.9 to 26.3 ppt) with no pronounced stratification. It is also noteworthy that overall ebb-tidal salinity values were lower than flood-tidal values. The contour maps for August again showed a tendency for less saline waters on the west side of the harbor and more saline waters on the east side. By September, Sound waters had higher salinities, averaging around 25 ppt at the harbor mouth on both phases of the tide. More stratification than during the summer was apparent near the head of the estuary (down to 15 ppt on the ebbing tide) as a consequence of increased runoff. By October, the salinities of Sound waters were dropping again (down to 26-27 ppt), strong stratification was again apparent in the inner harbor on flood and ebb tides, and runoff was increasing to typical seasonal levels.

Temperature Distribution for the Sample Year

Temperature, in addition to salinity, plays an important role in harbor hydrodynamics and in determining the distribution of biological communities.

In general, inner harbor stations have the highest temperatures as well as the greatest tidal temperature variations. The mean temperature for 17 stations over the sample year was 12.3 C, with a minimum monthly mean of 1.3 C and a maximum of 26.6 C. Maximum values were recorded in July and August. Thermal stratification, as well as pronounced salinity stratification, was evident during April at nearly all ebb-tidal survey stations. Little thermal variation with depth, tide or station location was seen during other monthly surveys. Exceptions were at Station 2, near United Illuminating Company's English Station discharge, and at Station 8, near the New Haven Harbor Station. At both of these locations, temperatures higher than ambient conditions were occasionally observed.

Data from the sample year (November 1976 through October 1977) showed details of annual temperature variations in the Harbor (Figures 3-5, 3-7). In November, Long Island Sound waters along the axis of the main channel near the harbor mouth were isothermal (7.5 C). Some elevated temperatures (8.0 to 8.5 C) were observed in the middle of the harbor during ebb tide, possibly corresponding to the Harbor Station discharge plume. Near the head of the estuary, conditions were isothermal and identical to those at the harbor mouth on both phases of the tide (7.5 C). By December, temperatures had dropped sharply. Long Island Sound waters and those of the outer harbor were generally isothermal (at 3.5 C), whereas near the head of the estuary temperatures were somewhat lower (2.5 C). At a few locations, the water column was thermally stratified, with the coldest water at the surface. Due to the severe cold weather, and attendant freezing, January data are incomplete. Ebb tide temperatures were 0.0 C and colder.

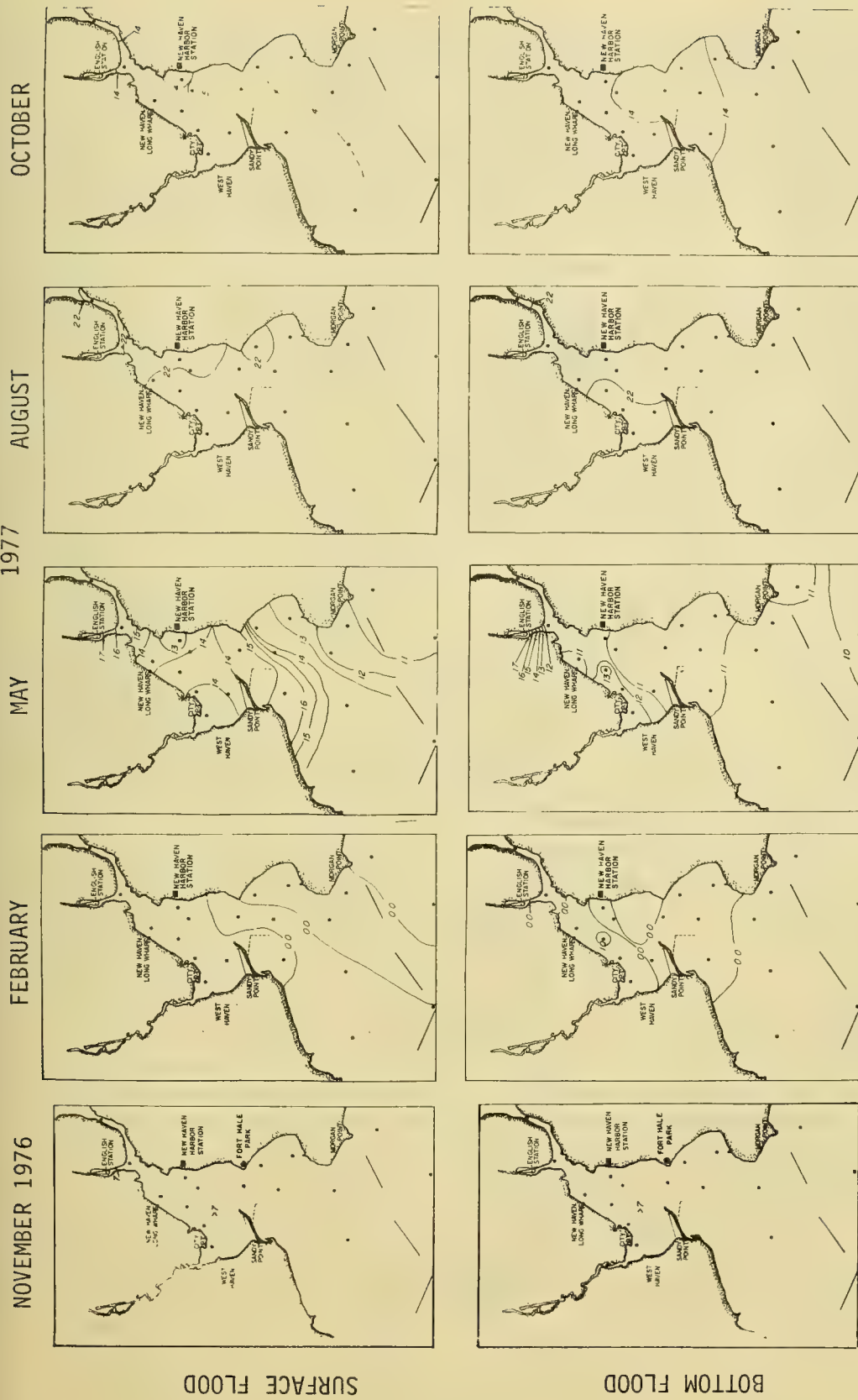


Figure 3-7. Surface and bottom, flood and ebb tide temperature contours for November 1976 and February, May, August, October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

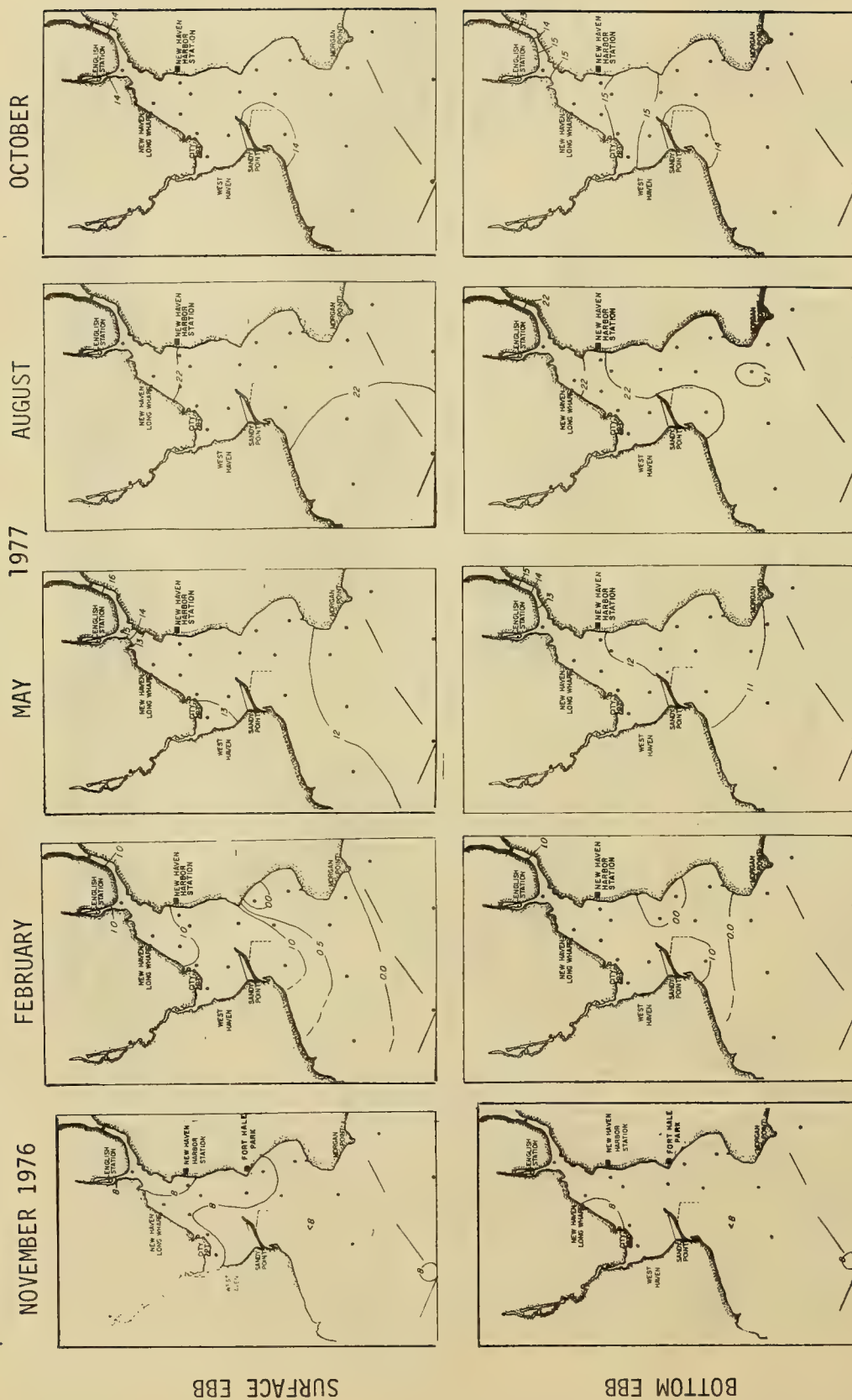


Figure 3-7. (Continued)

By February, temperatures in the outer harbor and adjacent waters of Long Island Sound were as low as -0.5°C . Waters of the inner harbor were slightly warmer (up to 1.0°C). The surface temperature maps show that warmer inner harbor waters tended to occupy the western side of the harbor whereas the eastern side was dominated by the colder Long Island Sound waters.

March cross-sectional data show the cold isothermal conditions of Long Island Sound at the harbor mouth (Station 20) (average temperature was 3.0 to 3.5°C). Within the inner harbor, a warmed near-surface layer about 1 m thick of up to 6.5°C was clearly evident. Near the head of the estuary on the ebbing tide, warm, low-salinity waters from upland drainage were flushed into the main harbor near Station 3 and formed this surface layer. On the flooding tide, this warmed water became trapped on the western side of the harbor and colder, more saline waters intruded landward into the upper estuary. By April, seasonal warming of Long Island Sound waters was well established, with average temperatures of 8.0 to 9.0°C . Ebb-tidal temperatures were up to 14.5°C at Station 1 and the stratified layer across the inner harbor was almost 2 m thick. The pattern for May remained about the same except that temperatures had increased by a few degrees (to 10.5 to 11.5°C) at the harbor mouth and up to 16.0°C in the Quinnipiac (Station 1). On the flood tide, the warmed inner harbor waters from the preceding ebb tide moved toward the western half of the harbor.

In June, Long Island Sound waters developed strong thermal stratification, averaging 17.5°C near the surface and 14.0°C near the bottom (Figure 3-5). Across the inner harbor, temperatures were higher, but vertical gradients were less distinct due to greater mixing and a weak halocline. In July, the Sound showed a fairly thick, warm near-surface layer (21.0 to 22.7°C) and cool near-bottom waters (19.0 to 20.0°C). Land runoff on the ebbing tide was up to 26.0°C , but the isotherms indicated weaker stratification and more vertical mixing across most of the harbor.

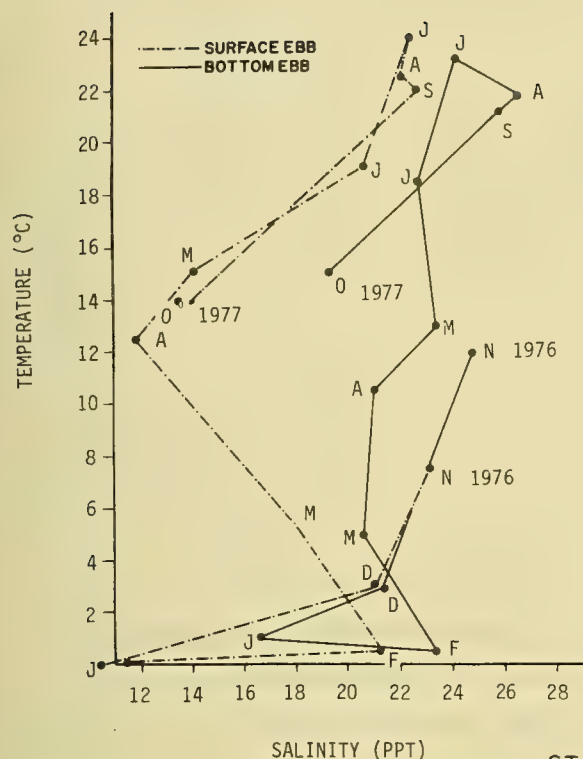
By August, conditions had changed dramatically. The edge of Long Island Sound at Station 20 was essentially isothermal, ranging from 21.2 to 22.0 C. Likewise, the entire harbor showed essentially no stratification, nor was there much variation between flood tide and ebb tide. This uniformity is also evident in the temperature contour maps. September conditions showed almost identical patterns, but temperatures were already starting to drop slightly with the passage of summer. With increased storm activity and runoff in the fall, October temperatures dropped sharply to 14.5 C in the Sound and outer harbor and 13.0 to 13.5 C near the head of the estuary. Conditions were quite uniform from station to station, with very little difference between tidal phases.

Temperature-Salinity: Patterns of Density Changes During the Sample Year

The inner harbor waters, as typified by the data collected at Station 3, showed a sharp contrast between near-surface and near-bottom waters for both flood tide and ebb tide (Figure 3-8). Near-bottom waters cooled rapidly throughout the winter, starting in November and reaching minimum values in February. A slight January thaw was reflected as an ebb tide freshening. In March and April, salinities declined and temperatures increased sharply. Through July, temperatures continued to rise as salinities increased at the surface and were stable near bottom. In July and August, both the highest temperatures and the highest salinities were observed. Through the fall, temperatures dropped rapidly and salinities decreased slightly. This pattern for near-bottom waters is remarkably consistent for both tidal phases, but ebb-tidal conditions were sometimes 5 ppt fresher than flood-tidal conditions (Figure 3-8).

Near-surface waters overall had much lower salinities and slightly higher temperatures than near-bottom waters, but the annual

STATION 3



STATION 20

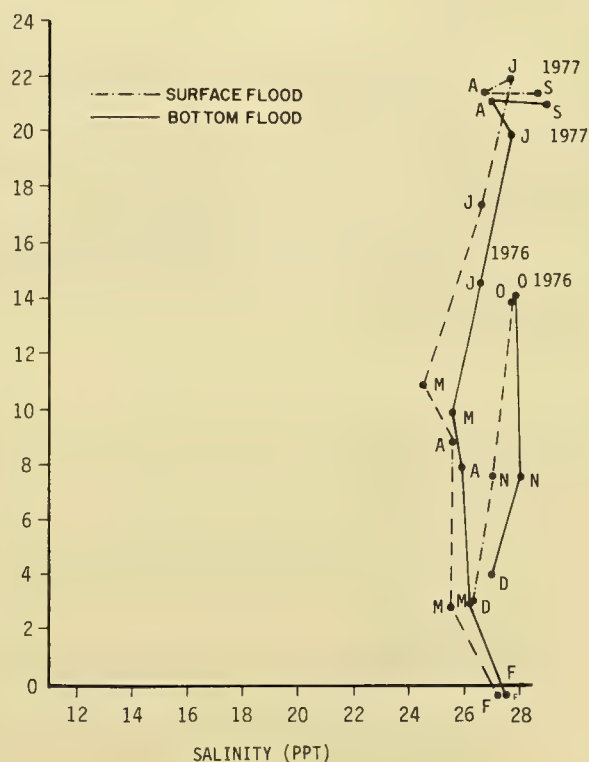
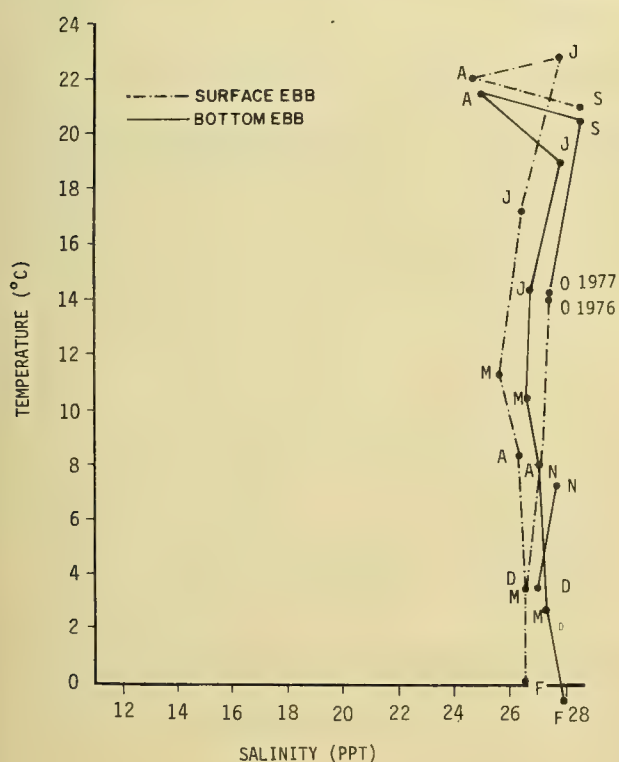


Figure 3-8. Temperature vs salinity, Stations 3 and 20, surface and bottom, flood and ebb tides, October 1976-October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

cycle was very similar. At this station, the lowest salinities occurred in March and April and the highest in July, August, and September. Lowest near-surface temperatures were observed in January and February whereas the highest occurred in July. Month-to-month temperatures between flood and ebb have been quite similar, but ebb-tidal salinities were 2 to 6 ppt fresher than flood-tidal conditions (Figure 3-8).

The waters of the outer harbor at the periphery of Long Island Sound (Station 20) are much less variable from near-surface to near-bottom and flood tide to ebb tide (Figure 3-8). The annual cycle starting in November showed relatively constant salinities and decreasing temperatures through February. Temperatures then rose through July, while salinities dropped to the lowest levels of the year in May and August. Temperatures were relatively stable July through September, then decreased with relatively constant salinity through October. Ebb-tidal salinities tended to be about 1 to 2 ppt lower than flood-tidal values.

These data show that runoff from land drainage plays a major role in driving circulation by establishing salinity gradients within the New Haven Harbor estuary. The more saline, colder Long Island Sound waters tend to intrude landward at depth. Some of this water mixes with the near-surface waters at the head of the estuary and returns seaward to complete the cycle.

Dissolved Oxygen Distribution

Dissolved oxygen (DO) is a critical factor affecting the distribution and abundance of aquatic organisms in New Haven Harbor. Variability of conditions within the Harbor is caused by the combined influence of ambient temperatures and biological fluctuations, industrial discharges, and sewage effluents.

The physical/chemical studies for the New Haven Harbor Station Ecological Monitoring Studies program have shown a pronounced annual

cycle (Figure 3-9). Peak levels occurred in January and February (up to 14.0 to 15.0 mg/l); values then declined to minimum levels in July, August, and September and returned to peak values by December. The most unfavorable dissolved oxygen conditions occurred at the confluence of the Mill and Quinnipiac Rivers, but all three of the innermost stations (Stations 1, 2 and 3) had numerous dissolved oxygen readings in the unacceptable (<4.0 mg/l) range.

pH Distribution

Average pH in New Haven Harbor was 7.6, with a maximum of 9.7 and a minimum of 6.0 (Figure 3-10). There are no indications that fluctuations of pH are correlated with depth, tidal phase, or station location. Because of the considerable neutralizing potential of the saline waters, pH is generally an insignificant factor in the ecology of New Haven Harbor.

Summary data from Station 3, representing conditions in the inner harbor from 1971 through 1977, show mean values between 6 and 9 (Figure 3-10). Flood-tidal conditions have tended to be quite uniform with slightly lower values near the surface than near the bottom. Ebb tidal conditions showed more variability, with readings in July 1975 as low as 6.0.

Waters in the outer harbor at Station 20 showed average pH values between 7 and 9 (Figure 3-10). At this location, there is little variation between flood-tidal and ebb-tidal conditions, but near-surface values tend to be slightly higher than near-bottom values.

Continuous measurements from the Honeywell Water Quality Monitor located on the pier off the New Haven Harbor Station showed little variation in pH on both a daily and seasonal basis. Because of its uniformity, pH does not appear to have been an important controlling parameter in New Haven Harbor.

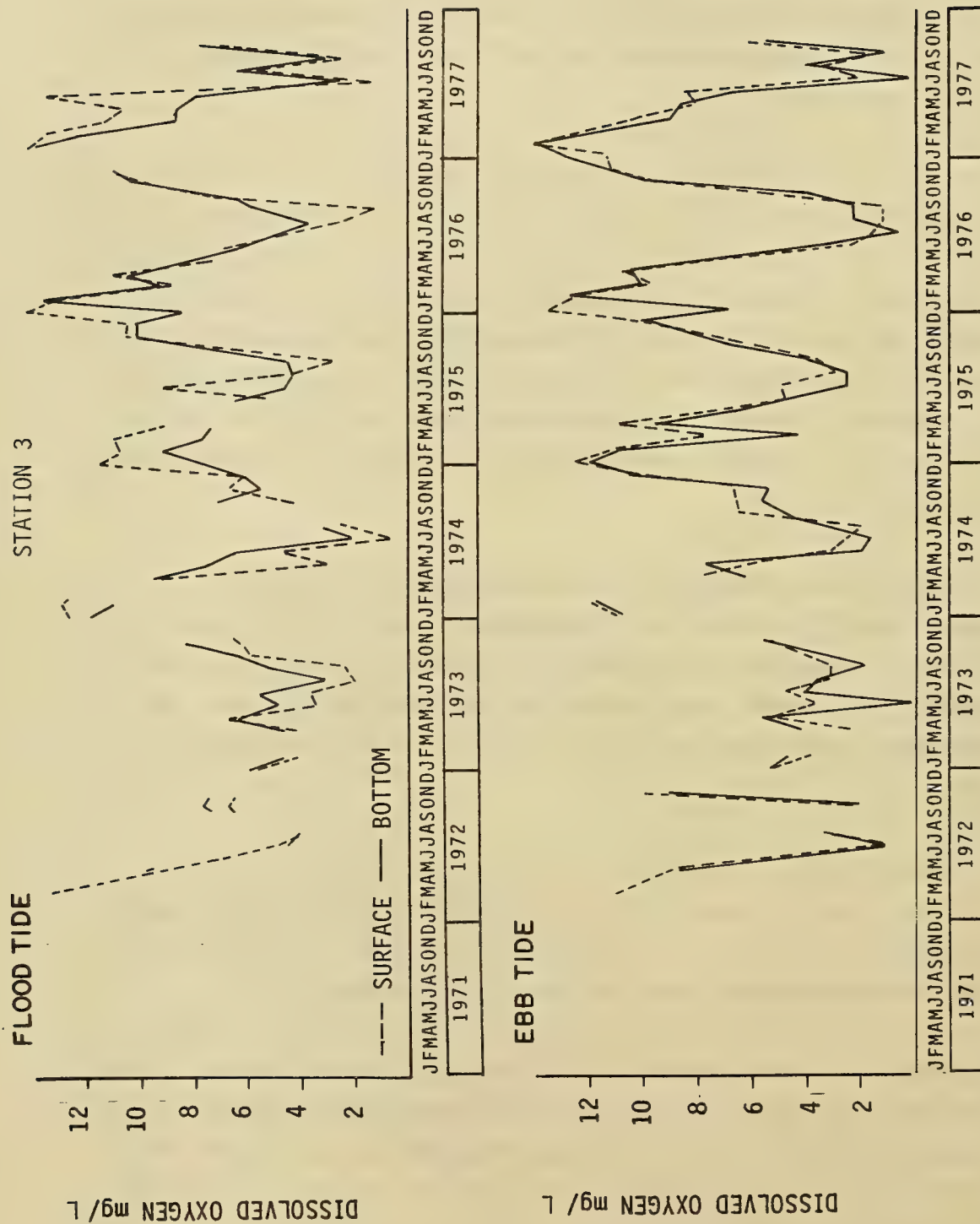
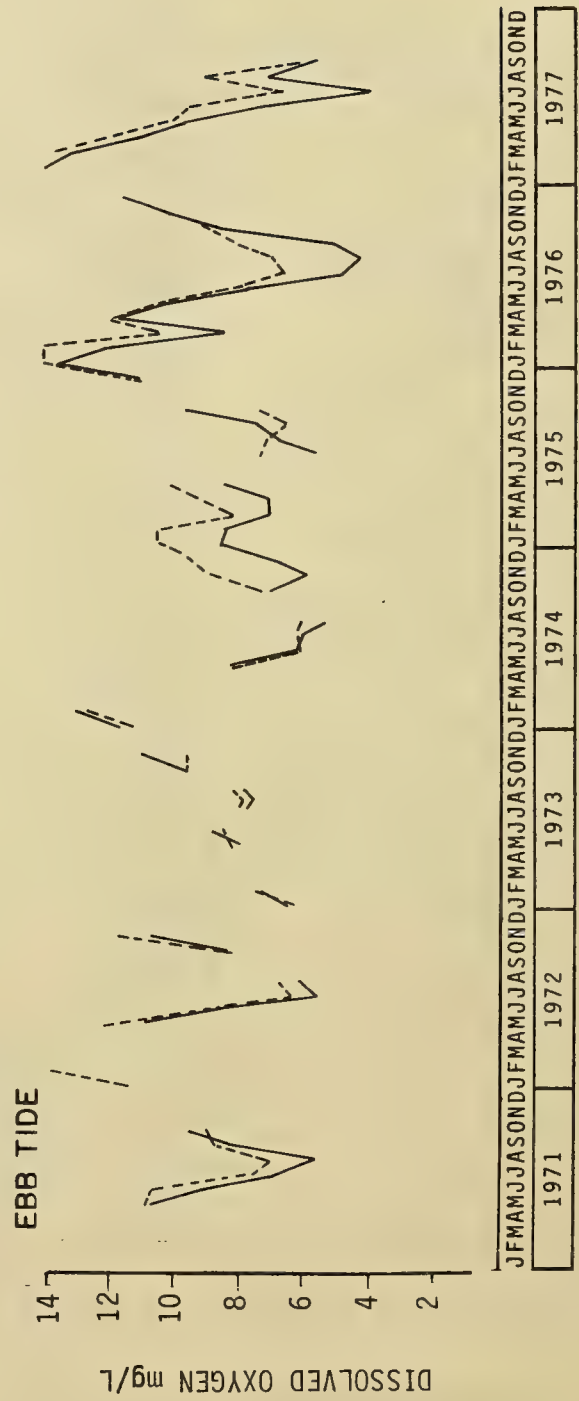
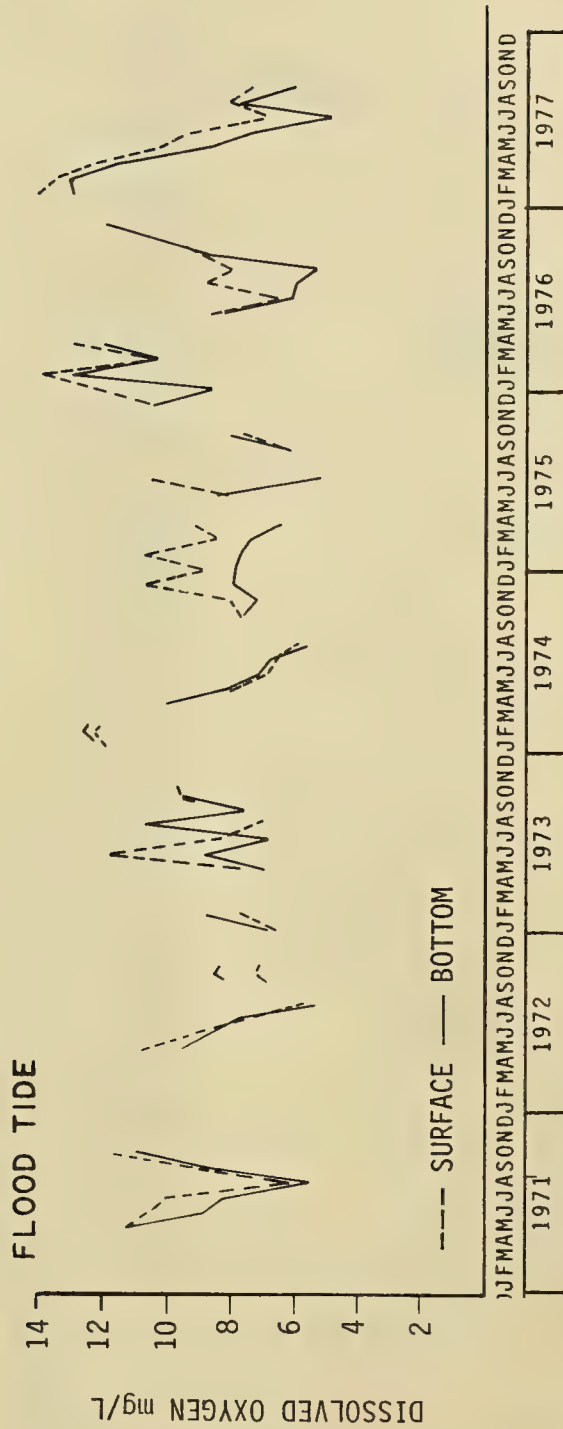


Figure 3-9. Monthly surface and bottom dissolved oxygen (mg/l) by tide and depth, Stations 3, 8 and 20, from May 1971 through October 1977. New Haven Harbor Station Ecological Studies Summary Report, 1979.

Continued

STATION 20



Transparency

Water transparency data, as measured by Secchi disc, showed that New Haven Harbor is a relatively turbid estuary. Typical values ranged from 0.2 m to 2.3 m with a mean of 1.1 m. Transparency was slightly greater in the outer harbor than in the inner harbor. Transparency is affected by various factors, including phytoplankton abundance, suspended particulate matter, dissolved materials, and incident light. Thus, transparency was only used as a qualitative indication of depth of the photic zone; no attempt was made to link observations to specific causative factors.

Spatial Variability Patterns

The waters of the inner harbor show a relatively wide variation of physical/chemical parameters over the course of any tidal cycle, season, or year (Figure 3-9, 3-10, 3-11, 3-12). Salinity, dissolved oxygen, and temperature measurements show a tendency for waters from near the head of the estuary to flush seaward on the ebb, sometimes temporarily being trapped in an eddy on the western side of the harbor.

The waters of the outer harbor adjacent to Long Island Sound show very little variation from flood to ebb tide, but undergo a systematic annual cycle (Figures 3-9, 3-10, 3-13). Thus, the outer harbor shows relatively free exchange with Long Island Sound, and a tendency for such waters to occupy the eastern side of the inner harbor throughout the tidal cycle is noticeable.

Quinnipiac River

Station 1 in the lower reaches of the Quinnipiac River, showed the highest variability of salinity, temperature, dissolved oxygen,

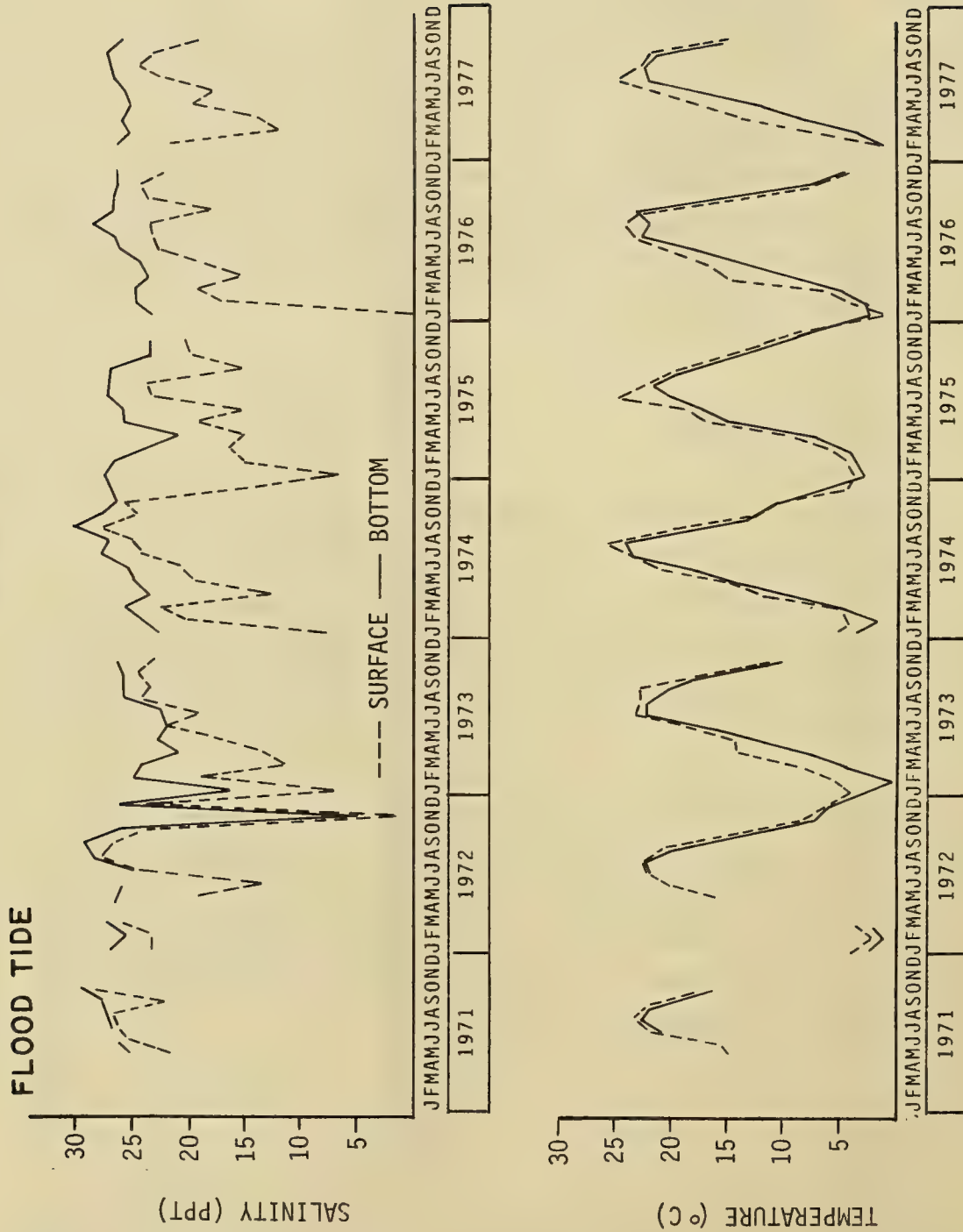


Figure 3-11. Monthly surface and bottom salinity and temperature data from Station 3, flood and ebb tides, in New Haven Harbor, Connecticut. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

STATION 20

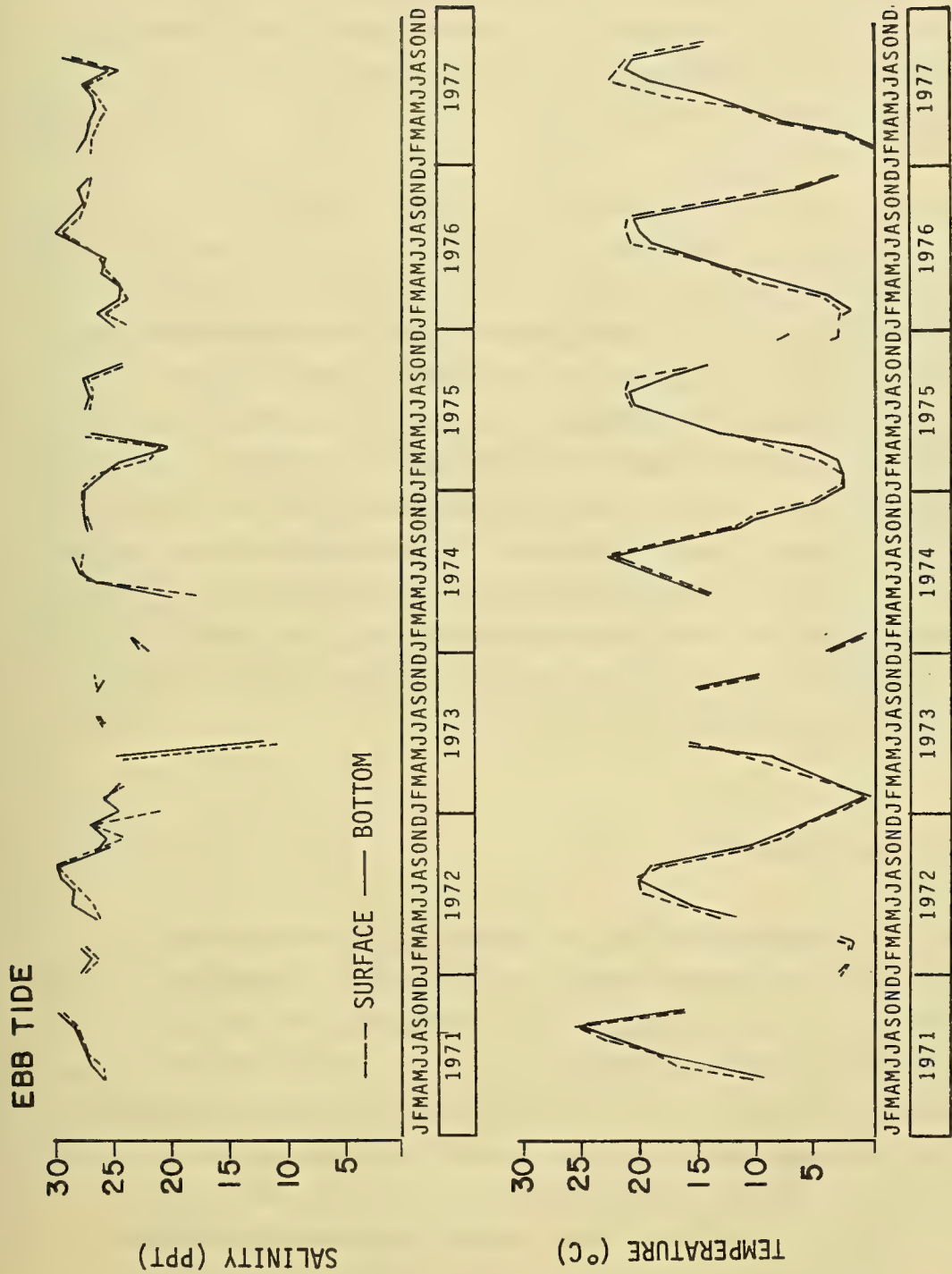


Figure 3-13. (Continued)

and pH in the harbor. These changes were coincident with periods of high or low freshwater flow from the river, which warms in the spring and cools in the fall more quickly than the harbor waters, and which governs salinity in most of the harbor. Quinnipiac River flow dilutes harbor water progressively less as it mixes toward Long Island Sound; its dilution effects were most evident in the river itself.

Mill River

Because of its low flow rate and extensive industrialization (Fisher, 1974), Mill River waters are the most deteriorated of those entering New Haven Harbor. Low freshwater flow minimizes flushing, so that water which has been contaminated from the East Street sewage treatment plant and by industrial wastes is impounded in the Mill River on successive tidal cycles. This impoundment causes further deterioration of water quality by exposure to grossly polluted sediments (NAI, 1974c) and to heating by the English Generating Station. The highest temperatures, most variable pH, and lowest dissolved oxygen and transparency were found in the Mill River (Station 2).

Mill-Quinnipiac Confluence

The harbor proper begins at the confluence of the Mill and Quinnipiac Rivers, and the marine waters clearly dominate the hydrography and water quality of the area. Freshened waters from the Quinnipiac (which is tidal far above Station 1) commonly cause a "salt-wedge" structure at Station 3; this is most prominent during periods of high runoff. Salinity may differ by more than 10 ppt between surface and bottom (7 m, MLW). The Mill River contributes turbid, heated water with variable pH and low dissolved oxygen concentration to this site on the ebbing tide. During flood tide, East Street sewage effluent flows up to the site, and into the Mill River as well. High temperatures,

highly variable pH, and low dissolved oxygen and transparency were characteristic of the confluence. The influence of runoff on salinity and temperature was always evident there.

Long Wharf Shore

The Long Wharf Shore area extends from the East Street sewage treatment plant to City Point and was sampled at Stations 4 and 5. This area is influenced by the sewage treatment plant discharges at its north and south boundaries, flow from the Mill-Quinnipiac confluence and West River, and eddy circulation as documented by Duxbury (1963) and confirmed by NAI (1974a). The area is characteristically shallow (3-6 m, MLW) and is typically less influenced by runoff than the head of the estuary. We observed peak summer temperatures in this area which were sometimes 1-2 C warmer than the rest of the inner or outer harbor. Salinity, dissolved oxygen, and pH were less variable than at the Mill-Quinnipiac confluence but still occurred over a very broad range. Low summer dissolved oxygen concentrations were similar to those found upstream.

West River Mouth

Station 6 was located near the mouth of the West River in the shallow (4m, MLW) West River Channel. Only during peak runoff periods did this area differ substantially from the Long Wharf Shore area; at these times, salinities 3-5 ppt lower than adjacent areas were observed in the West River mouth area.

Inner Harbor Shipping Channel

Two stations (8, 9) were situated near the shipping channel just off New Haven Harbor Station in 13 and 7 m (MLW) of water, respect-

ively. This area was slightly stratified with respect to salinity and temperature except in midsummer, when runoff was minimal. Transparency and dissolved oxygen concentrations were higher than in the balance of the inner harbor; pH, salinity, and temperature fluctuations were less because of the greater depth and proximity to the outer harbor.

Inner-Outer Harbor Boundary

The division between inner and outer harbors occurs at the natural constriction formed by Sandy Point on the West and by Fort Hale Park on the East. Our sampling indicated that this boundary was typified by characteristics intermediate to those of the inner and outer harbors. This boundary zone was sampled at Station 11 in the main shipping channel in 12 m of water (MLW). Except in cases of extremely high runoff, there was little difference between the inner harbor shipping channel area and this boundary location; when runoff was extreme, horizontal and vertical salinity gradients were observed that were unique to this boundary area, i.e., they differed from both the inner and outer harbors proper.

Morris Cove

Morris Cove is shallow (3-4 m, MLW) and has strong ebb-tidal currents (Duxbury, 1963) that carry inner harbor waters into the outer harbor and Long Island Sound. The cove is typically well mixed and similar to Long Island Sound, except on ebb tides during periods of substantial runoff, when near-surface dilution is extensive. Morris Cove faces a long southwest fetch; when southwest winds persisted for a few days, supersaturation (>150%) of dissolved oxygen was observed in near-surface waters. Biological productivity might contribute to this phenomenon.

Sandy Point

South of Sandy Point, a shallow station (Station 15, 2 m, MLW) was monitored which was atypical of the rest of the harbor. High surface temperatures, low salinities, and variable dissolved oxygen concentrations characterized this station. We believe that these conditions were due to at least three causes: 1) West Haven Sewage Treatment Plant discharge; 2) eddy entrapment of ebb tide water during flood tide; and 3) transport of inner harbor waters around or over Sandy Point to this area during ebb tide.

Outer Harbor Proper

Outer harbor stations (16, 18) showed a slight harbor influence, particularly by exhibiting reduced surface salinity during periods of peak runoff. Otherwise this large area was not distinct from adjacent Long Island Sound.

Long Island Sound

No saline stratification was observed in this area. Dilution by fresh water was uniform throughout the water column, since the Connecticut River, the major freshwater source for Long Island Sound, measurably dilutes much of North Central Long Island Sound during the spring freshet (Riley, 1952). Thermal stratification was uncommon but did occur briefly in July 1977. Dissolved oxygen concentrations rarely fell below 7.0 mg/l; when this happened, it did not persist. Values of pH were stable and usually between 8.0 and 8.5. Transparency was generally greater than that observed within the harbor.

Comparisons Among Study Years

Meteorological parameters having the most influence on harbor hydrography are precipitation, incident solar radiation, wind and air temperature. We had no data on insolation; wind data was available but is related to estuarine hydrographic processes in such complex ways that no attempt was made to ascertain wind effects. Precipitation is added to Harbor waters via runoff, which integrates precipitation with the hydrologic characteristics and preconditions of the drainage basin. Monthly mean runoff and air temperature for the study period are shown in Figure 3-4, as is also monthly total precipitation. Annual differences in hydrographic parameters are generally climatologically induced. Annual patterns of surface, bottom, ebb and flood-tide temperature and salinity (Figures 3-11, 3-12 and 3-13), dissolved oxygen (Figure 3-9), and pH (Figure 3-10) were compared and notable differences are presented in Table 3-1. Also presented in Table 3-1 are climatological departures from the norm. Years are presented on a November-October basis, when the data permit, to facilitate comparison with the preceding detailed characterization of the sample year.

Most years had characteristic periods of reduced salinity and intense stratification corresponding to spring runoff and, when summer was not too dry, low salinity periods corresponding to fall rains, although the magnitude and timing of these periods varied considerably. Dry summers caused reductions in the ground water, so that fall rains were absorbed rather than released as runoff. Sampling began in May 1971; although precipitation was heavy in that month, preceding conditions had been so dry that runoff was minimal. Unusually heavy rains in July, August and September led to reduced salinity in September. In 1972, harbor salinity was low in June, due to a very wet spring. Because of a dry summer, no early fall salinity reduction occurred. However, heavy October rains led to low salinity in November. This wet period persisted through July 1973; consequently, low salinities were characteristic of January-June 1973. August through November was relatively dry and no fall salinity low was observed. December 1973 and January and March 1974 precipitation led to reduced salinities in the last of 1973

TABLE 3-1. SUMMARY OF CLIMATOLOGICAL AND HYDROGRAPHIC CONDITIONS, 1970-1977. NEW HAVEN HARBOR
ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	PRECIPITATION *	SALINITY †	AIR TEMPERATURE *	WATER TEMPERATURE †	DISSOLVED OXYGEN † CONCENTRATION	pH †
May 1970 - April 1971	Very low except November	---	High July - November	---	---	---
May 1971 - October 1971	High except low June, normal October	Low September	High September-October	Low May; high August	Normal	Normal
November 1971- October 1972	Very high January-June October; July-September low	Low June	High December-January	Low July, September, October	Normal	Normal
November 1972- October 1973	High November-July; August-October low	Low November, January-June	Low November; high March, June-October	High January-February; low November	Normal	Normal
November 1973- October 1974	November, April-August, October low; December, January, March, September high	Low December, March- May	High November-January, March-April, July- August; low October	Low October	Low winter	Normal
November 1974- October 1975	Low November, April, August; December- January, July, Sep- tember high	Low November, January- April	High November-January, May, August, October; low April	Low December, April	Low Fall-Winter	Normal
November 1975- October 1976	High January, August, October; low March- April, June-July, September	Low January-March	High November-December, February-April	High December	Low Fall	Normal
November 1976- October 1977	Low November-February, May, July; high March, September	Low March-April, October	Low December-January; high March, May, August-November.	Low December -February	August peak	Normal

* All comparisons are against 25-year means

† All comparisons are against 7-year means

and the spring of 1974. April-August and October-November were dry periods; September rains had no detectable effect on salinity regimes, although November salinities were reduced in the inner harbor (possibly because sampling coincided with a neap tide). December 1974-January 1975 precipitation caused reduced salinity from January through April. Despite a wet July and September, no fall salinity low occurred in 1975. Above average precipitation in January 1976 led to reduced salinities January-March; much of the rest of the spring and summer was sufficiently dry to preclude fall salinity minima. Rainy March and September 1977 were reflected in March-April and October salinity minima.

A salinity minimum period reflecting runoff conditions has occurred consistently between December and June; the duration, timing and extent of the period is dependent on climatology and hydrology of the drainage basin. Fall minima were apparent in 1971, 1972, 1974 and 1977.

Water temperatures were not similar to air temperatures in absolute terms, because conductive heat transfer across the air-water interface is small compared to radiational transfer processes. However, since the same radiational effects govern air and water heat transfer, variation in patterns of air and water temperature are grossly similar.

In 1971, there was no atmospheric correspondence with unusually low May and high August water temperatures. In turn, unusually warm September and October air temperatures had no apparent effect on water temperature. A relatively mild winter 1971-1972 saw normal water temperatures; summer and fall 1972 waters were colder than in other years, while air temperatures were normal for those seasons until November, when they were below average. In January and February 1973, the harbor was unusually warm, though no comparable climatological pattern occurred. Despite a climatologically warm period that persisted from March 1973 through August 1974, no departure from normal water temperature was observed during this period. An unusually cold October 1974 was comparable for air and water. December 1974 was also cold in

the harbor, although weather in November-January was warm. Below average air and water temperatures occurred in April 1975. December 1975 was uncommonly warm in New Haven Harbor, as were air temperatures in November-December 1975. December through February 1976 was unusually cold, accompanied by widespread freezing of the harbor, corresponding with low air temperatures during this period.

Only in August 1971 was an unusually warm summer month reflected in water temperature measurements. In 1972, summer was exceptionally cool. Warm winters occurred in 1972-1973, and 1975-1976, while 1974-1975 and 1976-1977 were unusually cold. Cold falls were characteristic of 1972 and 1974. Only in 1971 did spring temperatures depart from normal, when May was unusually cool.

Dissolved oxygen concentration patterns varied little with four exceptions. The levels failed to reach typical annual peaks in winter 1972-1973 and in fall and winter 1973-1974. Also, the typical fall increase was delayed in fall 1976. In 1977, a midsummer peak occurred in August, between July and September minima; in other years, August dissolved oxygen concentrations were low and similar to other midsummer minima. No correspondence was detected between these altered annual patterns of dissolved oxygen concentration and climatological effects.

No seasonal, climatological or other pattern of significance was evident in pH data.

Summary: Characterization of New Haven Harbor Hydrography

Physical/chemical characteristics of New Haven Harbor studied were generally similar 1971 through 1977 (NAI, 1971; 1973; 1974a; 1974b; 1975a; 1976a; 1977a, 1978a). Salinity, temperature, and, to a lesser degree, dissolved oxygen reflected the various years' climatology. Winter 1977 was colder than winters of 1972 through 1976 (NOAA, 1978),

causing extensive freezing in the harbor during January and February. As a result of heavy rains, 1972 runoff was greater than other years, resulting in reduced salinity values. Spring and fall stratification due to spring snowmelt and fall runoff respectively were regular occurrences. Dissolved oxygen levels peaked in the colder months and during major phytoplankton blooms; minimum concentrations were observed in midsummer. Dissolved oxygen increased more slowly in 1974, 1975, and 1976 from summer minima to winter maxima than in other years. Transparency and pH did not vary substantially from year to year.

Winter temperature minima occurred in January or February and summer maxima occurred in July or August in all years. Temperature was most variable in the inner harbor, relatively remote from the moderating influence of Long Island Sound.

In all years, stratification patterns were primarily dependent on precipitation and runoff within the tributary basins. Temperature is less important than salinity in controlling density, and hence stratification; thus the river mouths and inner harbor were stratified most often and most dramatically. Relatively stable thermal stratification, typical of less well-mixed, deeper coastal areas, was not characteristic of New Haven Harbor in any years studied. This is indicative of a high degree of turbulent mixing due to wind and tidal effects in this shallow harbor.

Dissolved oxygen concentrations showed typical seasonality, with reduced levels in summer months. This summer reduction is caused by a decrease in oxygen solubility (which is inversely related to both temperature and salinity) and by increased BOD from heightened bacterial decomposition of organic wastes, which is also directly related to increased temperatures. In the inner harbor, there were many DO readings below 4.0 ppm in July, August and September in all years. Higher and less variable concentrations were typical of the outer harbor. Unusually high values in near-surface layers may be attributable to production of oxygen through active photosynthesis by phytoplankton, or to exceptionally strong turbulent mixing.

The pH measured during monthly sampling was generally within the normal range for natural estuarine waters, and showed no consistent spatial or temporal pattern but was most variable in the inner harbor, especially near the river mouths. The average values compiled in 1977 were not substantially different from the average values compiled from 1971 through 1976.

Water transparency measurements showed no marked trends. In general, extinction depths were similar over the seven years studied. Inner harbor waters were generally slightly less transparent than outer harbor or Long Island Sound waters.

ANALYSIS OF IMPACTS

The New Haven Harbor Station affects the hydrography of the harbor by its intake of water at one location and its subsequent discharge several hundred meters away. The water that passes through the plant is mixed and heated between intake and discharge. Possible impacts of this system relative to the physical/chemical or hydrographic factors of the harbor include:

1. Modification of local current and wave patterns
2. Modification of the thermal regime in the harbor.
3. Changes in dissolved oxygen concentration.
4. Increased turbidity.

Evidence for the occurrence of these impacts and evaluation of their extent is presented below.

Modification of Local Current Patterns

The momentum of the water entering the intake structure and leaving the discharge pipe must contribute to some degree to the local current patterns.

The intake structure draws cooling water from the easterly end of an intake channel 230 m in length which runs from the intake structure to a point 30 to 45 m from the eastern edge of the main shipping channel (Figure 1-3). The intake channel was dredged to a depth of 9 m below mean sea level and crosses the shallow area adjacent to the plant site. Piers north and south of the plant may restrict flow that is part of the main harbor circulation from entering the shallow waters surrounding the intake channel. Skimming walls on the intake structure limit flow immediately in front of the structure to depths greater than 2.5 m below mean sea level. It is reasonable to believe that water enters the intake structure and channel from the shallow water area between the piers as well as from the westerly end of the channel. During normal operations at 100% generating capacity with three cooling water pumps in operation, the design flow for the intake structure is $18 \text{ m}^3/\text{sec}$. Assuming conservatively that the shallow water area does not contribute to the condenser cooling water, all of the flow would enter from the westerly end of the channel; in this case impact on the main harbor circulation by entrainment of water which is part of that circulation would be at a maximum. If the flow was uniform over the cross-sectional area of the intake channel, current speeds of 8 cm/sec at low tide and 5 cm/sec at high tide would be needed to deliver the cooling water to the intake structure at the required rate. At the westerly end of the intake channel, the flow into the channel would add to the tidal current (amplitude 21 cm/sec) as is shown in Figure 3-14. Figure 3-14, a simple vector addition of the intake velocities and tidal current velocities, shows that at the beginning of the intake channel the maximum flood and ebb currents would be deflected by no more than 20° from their normal path (parallel to the main channel) and that at slack tide a current

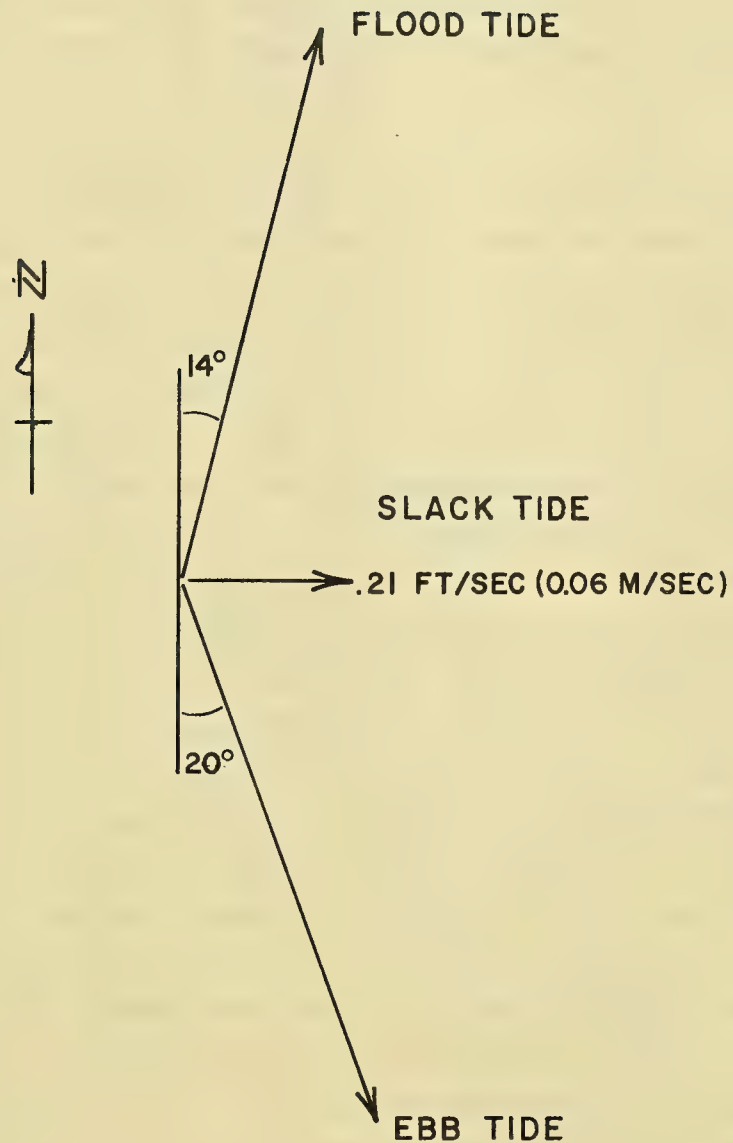


Figure 3-14. Vector sum of tide and intake current velocities at the entrance to the intake channel. New Haven Harbor Ecological Studies Summary Report, 1979.

which is about a third of the maximum tidal currents would be directed down the axis of the intake channel. This effect, which is the worst possible, would be limited to the width of the intake channel and the immediate vicinity of its westerly end. Further out toward the main channel, the intake velocities would decrease rapidly as the volume of water involved in supplying the cooling-water intake system increased. In the main channel, the intake velocities would be small and their effect on the tidal currents negligible.

To quantify the velocities and temperatures in the plume, a physical model was constructed and various tests were conducted by the Florida Engineering and Industrial Experiment Station (1972), and schematic representation of the behavior of the discharge plume is depicted in Figure 3-15. Figure 3-16 shows the determined velocity distribution along the axis of the plume. The speeds shown for the 37 to 43 m distances are the speeds measured in the area where the plume intersects the surface, the "boil area". Figure 3-16 shows these speeds to have been approximately 107 cm/sec. Flow-away velocities from the boil area are caused by the initial horizontal component of the momentum of the discharge and, to a lesser degree, by the density-induced convection as the lighter, warm water tends to spread over larger and larger areas. The maximum cross-sectional area of the flow-away velocity is small and is inversely proportional to the velocity (Table 3-2). To assess the magnitudes of the flow-away velocities, the scale of the model was changed from the 1:20 scale used to obtain the data presented in Figure 3-16, to a scale of 1:40. The results of the 1 to 40 scale test show that from the boil zone to the navigation channel the surface velocities were of the order of 61 cm/sec, reducing gradually to about 18 cm/sec near the opposite edge of the channel. The velocities of the discharge plume were directed primarily across the channel even during maximum flow in the channel (approximately 21 cm/sec). The reason for the cross-channel flow direction of the discharged water was that in the model basin the warmer water tended to ride on top of the cooler water where the main resistance to its flow was the interface friction, which had a relatively small effect on the discharge velocities. In the real

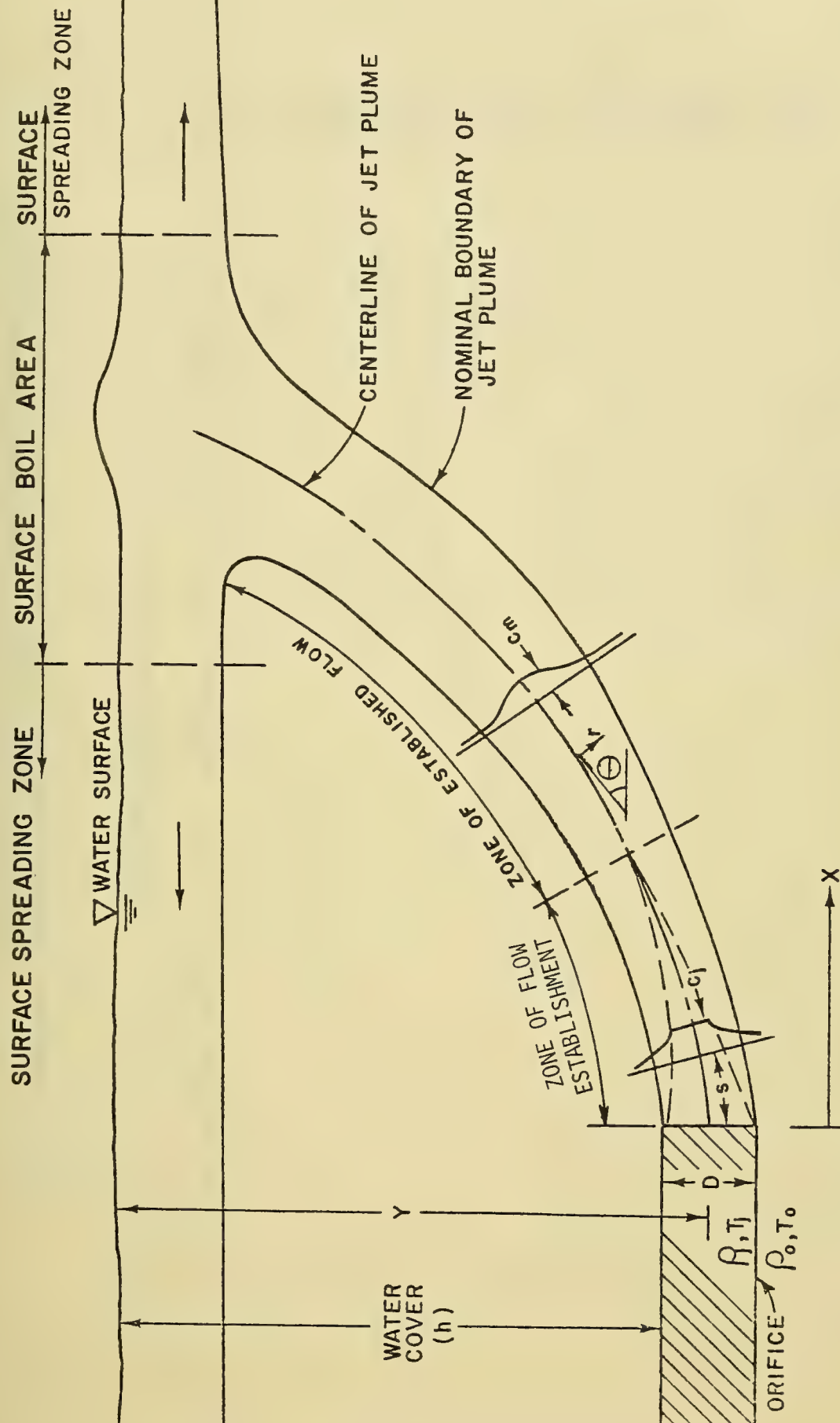


Figure 3-15. Definition sketch of University of Florida model tests. (From UFLA, 1972)
New Haven Harbor Ecological Studies Summary Report, 1979.

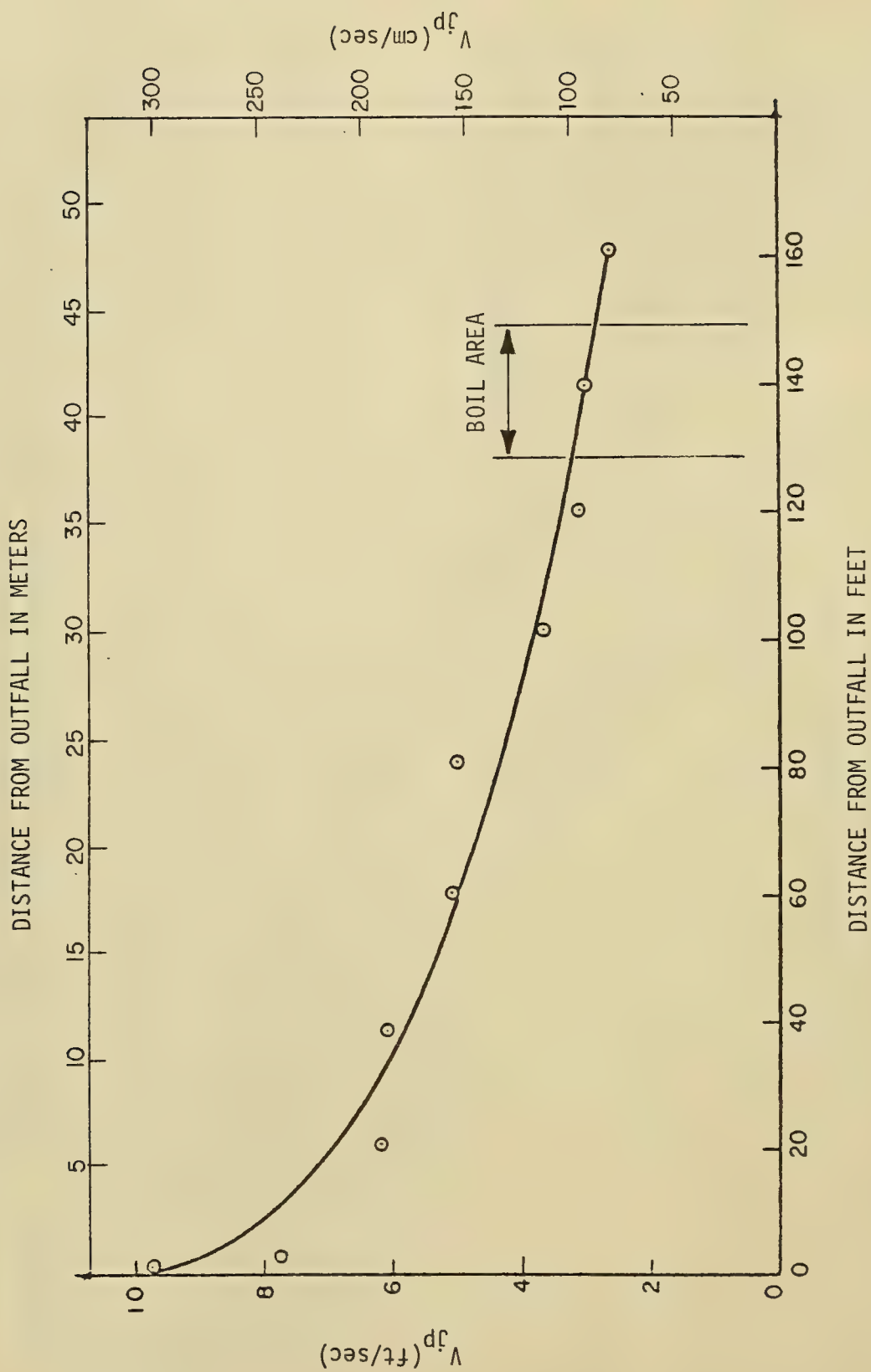


Figure 3-16. Velocity distribution along axis of plume (UFLA, 1972).
New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 3-2. MAXIMUM CROSS-SECTIONAL AREA OF DISCHARGE FLOW-AWAY
AT SELECTED VELOCITIES. NEW HAVEN HARBOR ECOLOGICAL
STUDIES SUMMARY REPORT, 1979.

VELOCITY (m/sec)	AREA (m ²)
107	16.6
100	19.3
61	29.1
21	83.0
18	96.8

situation, the salinity of the discharged water plays a major role in determining the density difference between the ambient water and the discharged water. As may be seen by examining the available data, this can alter the applicability of the model to the situation existing in New Haven Harbor.

In December 1977, a hydrographic survey was conducted during ebb tide. The stations for this survey are shown in Figure 3-1 and some of the results in Table 3-3. If the water below 2 m at Station 4 is fully mixed, the resulting temperature and salinity would be approximately 5.3 C and 22.4 ppt. We assume this mixing occurs in the generating station; thus, the discharged water would have a salinity of 22.4 ppt, a temperature of 13.6 C (5.3 C plus 8.3 C ΔT) and a corresponding density of 16.6 σ_t units. Table 3-3 shows the density at Station 8 at 1 m to be 10.5 σ_t units and at 10 m to be 19.6 σ_t units; thus, the density of the discharge water is intermediate to that of the water at 1 m of depth and that at 10 m. This means that at Station 8 the plume would not rise to the surface even though it is approximately 15 F (8.3 C) warmer than the surrounding water at discharge. The tendency for the plume to stay submerged is further increased by the fact that, as the water comes out of the discharge pipe, it is mixing with the deeper waters near Station 8, lowering its temperature and increasing its salinity and, thereby, its density. From this it is reasonable to believe that the rise in temperature at Station 8 at 3 and 5 m below the surface is due to a submerged plume; evidence of the plume at 3 m can be seen at Station 11 (Table 3-3). A submerged plume that mixes with the ambient water on all sides will have flow-away velocities that are lower than those predicted by the physical model, where mixing occurred only along the lower interface. The situation that leads to a submerged plume occurs primarily during the winter when there is marked salinity stratification.

Most of the time, however, the salinity stratification is not sufficient to result in a submerged plume. More normal conditions are those that existed during the thermal surveys conducted by NAI during

TABLE 3-3. RESULTS OF NAI HYDROGRAPHIC SURVEY DURING
DECEMBER 1977 - EBB TIDE. NEW HAVEN HARBOR
ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

STATION 4

DEPTH (Meters)	TEMPERATURE (C)	SALINITY (%)
SURFACE	4.0	5.6
1	5.0	13.9
2	5.0	20.6
3	5.0	24.1
4	5.5	24.1

STATION 8

SURFACE	5.0	12.6
1	5.0	13.2
2	5.5	22.0
3	7.0	22.7
5	7.0	23.4
10	5.0	24.8
11	5.0	25.5

STATION 11

SURFACE	5.0	11.9
1	5.0	15.9
2	5.5	19.9
3	5.7	22.0
5	5.5	24.1
10	5.5	24.5
12	5.5	24.8

July, August and October 1976. During these surveys, Rhodamine WT dye was added to the cooling water inside the generating station. Dye concentrations were converted to temperatures above ambient by assuming a direct relationship between dye dilution and dilution of discharged cooling water (NAI, 1976). No velocity measurements have been taken in the plume in New Haven Harbor, but by making some qualitative comparisons between the temperature dilutions measured during the thermal surveys and those predicted by the physical model, it is possible to get an idea of how reasonable it is to expect that plume velocities predicted by the physical model will be present in New Haven Harbor.

Figure 3-17 shows the results of the surface temperature measurements obtained from the University of Florida physical model. Shown are isotherms of degrees above ambient temperature with the out-flow located at 0.0. Figures 3-18 and 3-19 show the results of the NAI survey conducted during August. During the survey, the plume intersected the surface near the easterly edge of the navigation channel; the distance from the end of the discharge pipe to the inner and outer edges of the 4 F (2.2 C) ΔT isotherm are approximately 61 and 122 m respectively (the boil area must be somewhere inside this isotherm). Figure 3-17 shows the axis of the maximum temperature of the plume in the physical model intersecting the surface 53 m from the end of the discharge pipe. The temperature rise of the discharge water in the boil area in the physical model is also around 4 F (2.2 C); however, in this particular model run the temperature of the cooling water was increased to 10.3 C and the discharge rate lowered to 14 m³/sec. Exact comparisons between the test runs made with the physical model and the measurements made by NAI during 1976 and 1977 vary from test run to test run and between hydrographic and thermal surveys. This is not surprising considering the natural forces in New Haven Harbor that were not taken into account in the model (including wind and wave-induced turbulence), and the inherent limitations of a physical model. In general, however, one similarity and one difference between the results of the physical model test runs and what has been observed in New Haven Harbor are evident. The difference and similarity can be seen in Figures 3-17, 3-18 and 3-19

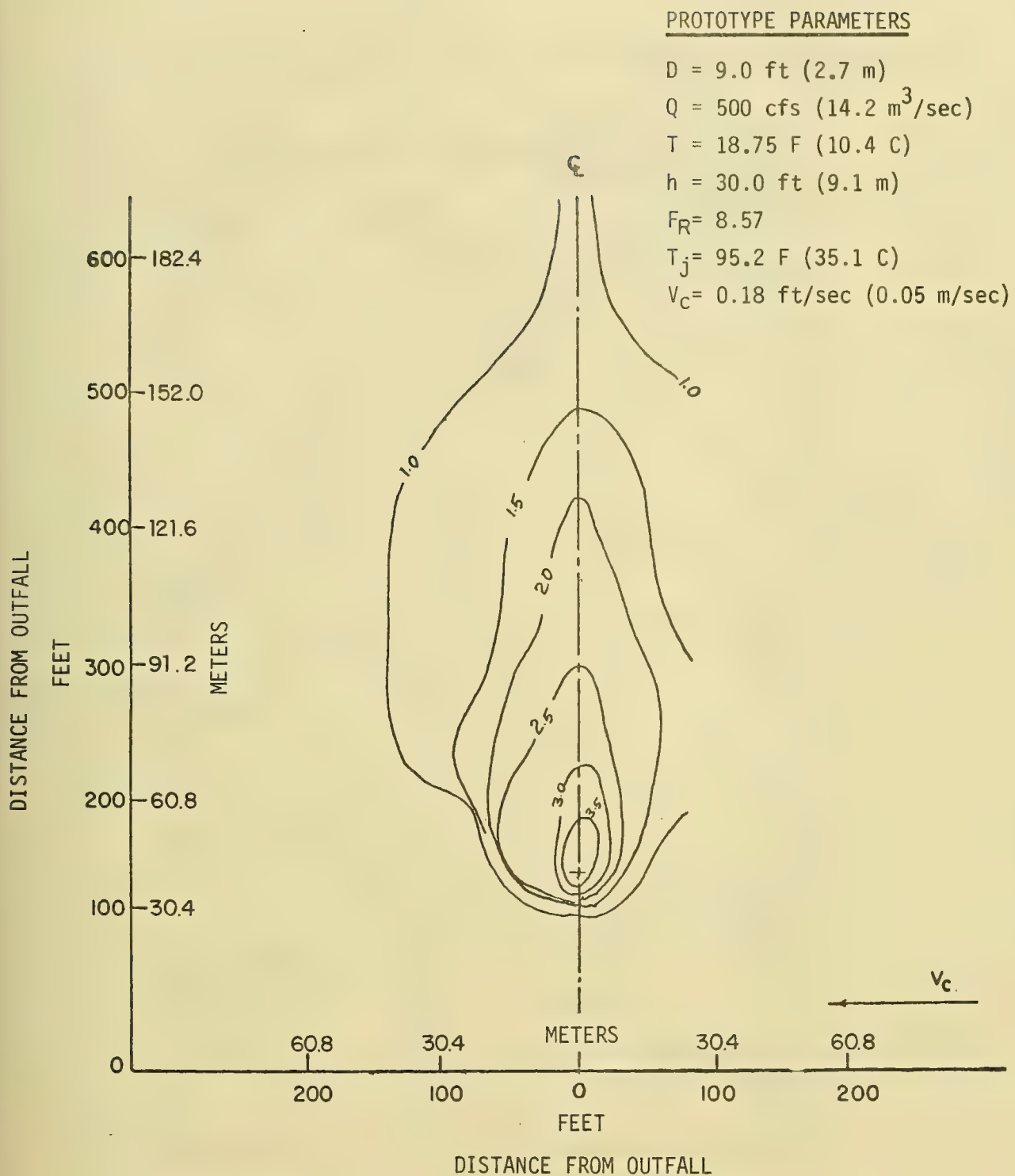


Figure 3-17. Surface isotherms, $\Delta T(^{\circ}\text{F})$ from UFLA, 1972. (1:40 scale)
 New Haven Harbor Ecological Studies Summary Report, 1979.

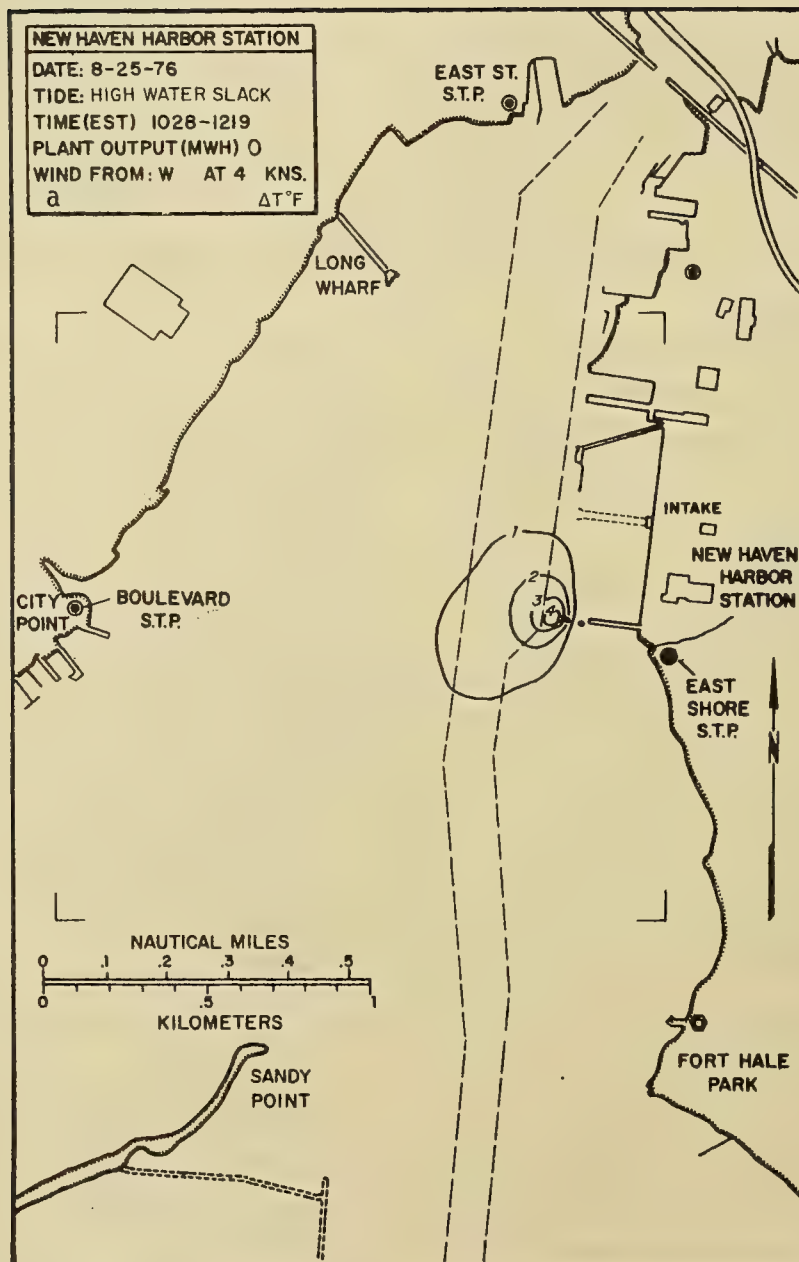


Figure 3-18. Projected surface ΔT ($^{\circ}F$) based on dye concentrations, high water slack, August 25, 1976, thermal survey. New Haven Harbor Ecological Studies Summary Report, 1979.

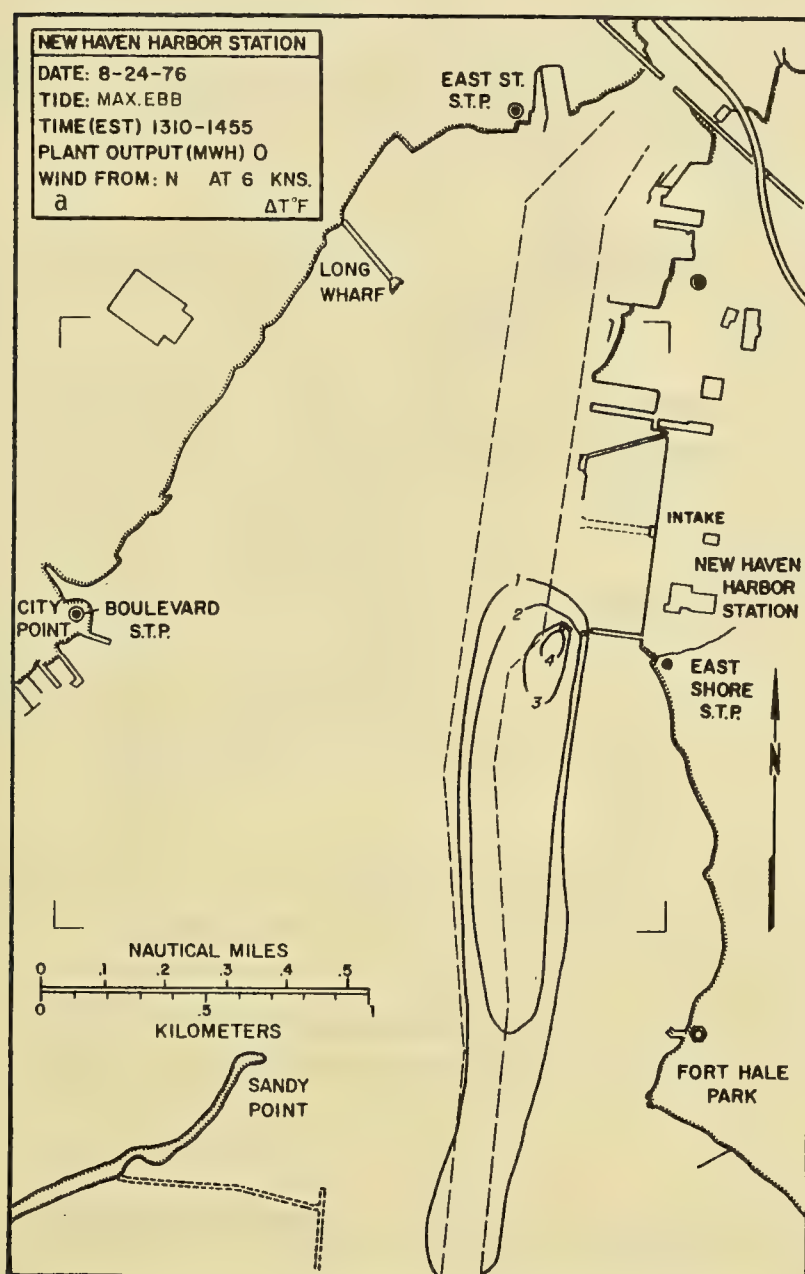


Figure 3-19. Projected surface ΔT ($^{\circ}\text{F}$) based on dye concentrations, mid ebb current, August 24, 1976, thermal survey. New Haven Harbor Ecological Studies Summary Report, 1979.

which show the plume in New Haven Harbor generally rising to the surface further from the discharge point than was predicted from physical model results and the temperature rise in the boil area being approximately the same as is seen in the physical model results.

The consistent delayed rise of the plume to the surface in New Haven Harbor is probably due to the fact that the mixing of salinities there does not create as great a density difference as was present in the physical model, which only took into account temperature differences. However, because the temperature rise in the boil area was predicted quite well by the physical model and because the plume seems to mix with the ambient water to approximately the same extent as was predicted by the model, we expect the plume to have momentum similar to model prediction when it reaches the surface of the harbor. Thus, the flow-away velocities found in the University of Florida model basin may reasonably be expected to be similar to those which are actually present.

The flow-away velocities of the discharge were limited to, and only measured at, the surface in the model. The potential of the discharge to affect the momentum balance in the inner harbor can be assessed by comparing the average momentum of the tide through the discharge location (Transect 1; Figure 3-20) with the momentum of the discharge.

The mean tidal height is 1.9 m. Assuming the stand of the tide is nearly synchronous throughout the harbor in region A (Figure 3-20) and that the tide can be represented as a one component sinusoid:

$$\left(\frac{dh}{dt}\right)_{\max} = \frac{2(.95 \text{ m}) \pi}{(12.4 \text{ hr}) (3600 \frac{\text{s}}{\text{hr}})} = 1.34 \times 10^{-4} \frac{\text{m}}{\text{s}}$$

where

$$\left(\frac{dh}{dt}\right)_{\max}$$

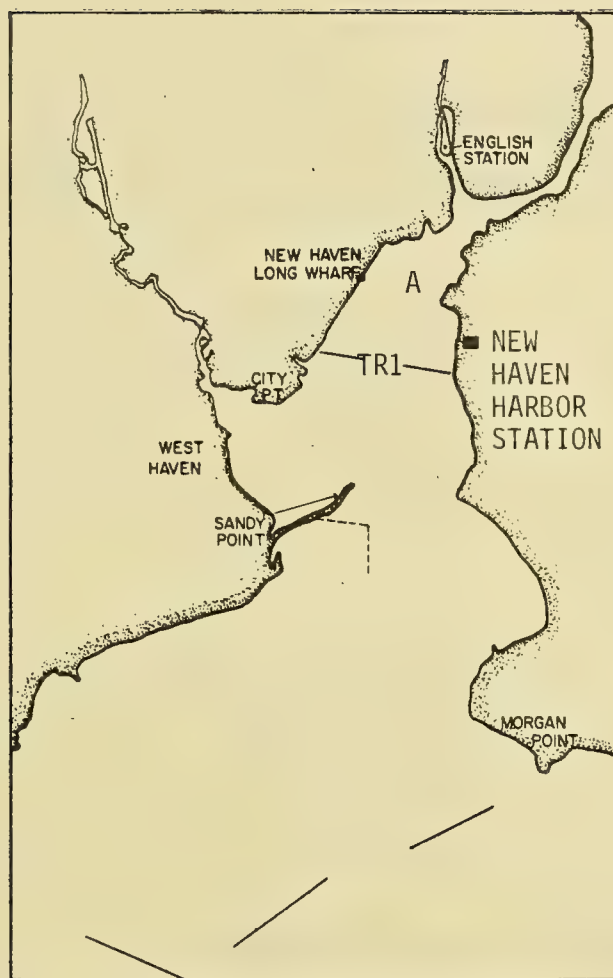


Figure 3-20. Transect for determining the tidal input of momentum to Section A during flood tide. New Haven Harbor Ecological Studies Summary Report, 1979.

is the maximum rate of change of the elevation of the sea surface. Since the current is approximately 90° out of phase with the tide height,

$$\left(\frac{dh}{dt}\right)_{\max}$$

occurs at same time as maximum tidal currents. The cross-sectional area of Transect 1 is $7.9 \times 10^3 \text{ m}^2$; therefore, assuming the current is perpendicular to the transect, the average maximum velocity through Transect 1 is:

$$\frac{(1.35 \times 10^{-4} \text{ m/s}) (2.7 \times 10^6 \text{ m}^2)}{7.9 \times 10^3 \text{ m}^2} = 4.6 \text{ cm/sec}$$

where $2.7 \times 10^6 \text{ m}^2$ is the surface area of region A (Figure 3.4-8) at mid-tide. The spatial average of the current through Transect 1 in cm/sec can be represented as:

$$V_{\text{avg}} = 4.6 \cos \frac{2\pi t}{12.4}$$

The root-mean-squared velocity is 0.707 times the amplitude; therefore, during flood or ebb tide, the average momentum of the water integrated over the cross-sectional area of Transect 1 is:

$$(4.6 \times 10^{-2} \text{ m/s}) (0.707) (7.9 \times 10^3 \text{ m}^2) (1.02 \times 10^3 \text{ Kg/m}^3) = 2.62 \times 10^5 \text{ Kg/s}$$

The momentum at Transect 1 due to the discharge from the station, integrated over the cross-sectional area of the discharge pipe is:

$$(17.7 \text{ m}^3/\text{s}) (1.02 \times 10^3 \text{ Kg/m}^3) = 1.8 \times 10^4 \text{ Kg/s}$$

Thus, the contribution of the tidal currents to the momentum balance through a narrow transect in the inner harbor is over ten times greater than that of the cooling water discharge. The relative importance of tidal currents increases rapidly as one moves away from the discharge point.

To further put the magnitude of the discharge in perspective, we calculated the total kinetic energy (KE) of the discharge, which can be calculated for one phase of the tide as:

$$KE = 1/2 mv^2$$

where m equals the mass of the water entrained over 6.2 hours and v equals the discharge velocity.

$$KE = 1/2 \cdot 3.92 \times 10^8 \text{ Kg} \cdot 9.3 \text{ m}^2/\text{sec}^2 = 1.8 \times 10^{16} \text{ ergs}$$

We then calculated the potential energy (PE) of the tidal prism, which is discharged as kinetic energy in tidal currents and friction:

$$PE = mgh$$

where m equals the mass of the tidal prism, g equals the acceleration due to gravity and h is the integrated head of the tide above mean low water.

$$PE = (5.0 \times 10^9 \text{ Kg}) \cdot (9.8 \text{ m/sec}^2) \cdot (0.95 \text{ m}) = 4.66 \times 10^{17} \text{ ergs}$$

Thus, the mechanical energy added to the harbor circulation by the Harbor Station's circulating pump system is approximately 4% of the energy attributable to the rise and fall of the tides.

Flow-away velocities of the cooling water discharge plume discussed above result in currents persisting primarily in a narrow band, 15 to 30 m wide. They do not pose any problem to larger vessels, nor any direct hazard to smaller craft, but can cause some deflection of small craft from their courses. For example, a boat traveling at 10 knots ($5.1 \times 10^2 \text{ cm/sec}$) might drift sideways 4-5 m while passing across the full width of the current zone. This is a minor effect when compared to the effect of a strong crosswind. Boats close together are not driven together by the current, since they are both affected by it.

Surface waves of about 8 cm in height have been observed in the boil area as a result of the discharge. They pose no hazard to ships or boats of any kind.

Water velocities associated with the intake have also been discussed above. The resulting currents are out of the main paths of ships and boats using the harbor and are of insignificant velocity in terms of their effect on navigation.

In summary, the intake and discharge of cooling water at the maximum design rate:

1. makes a small contribution to the momentum balance in the inner harbor and a minor addition to the kinetics of the harbor as a whole, and therefore is not expected to have an effect on the large scale circulation patterns.
2. could result in maximum velocities in the intake channel of 8 cm/sec at low tide and 5 cm/sec at high tide, and cause the peak tidal currents at the westerly end of the intake channel to deviate from their normal direction parallel to the axis of the main channel by less than 20° to the east; this effect decreases rapidly away from the intake channel and is negligible in the main channel of the harbor.
3. can cause surface currents directed in a narrow band, cross-channel at the discharge location, that are estimated to be from 61 to 91 cm/sec on the easterly edge of the navigation channel, falling to 18 cm/sec near the opposite edge of the channel. The cross-sectional areas affected by these currents are small. On rare occasions during the winter, these velocities may occur below the surface (submerged plume).

Modification of the Thermal Regime in the Harbor

When operating at 100% capacity, the thermal load on the harbor from the generating station is 2160×10^6 BTU/hr (545 Kcal/hr). Some of this discharged heat is flushed into Long Island Sound by the tide, and some is transferred to the atmosphere. If harbor temperatures do not rise to the temperature of the discharged water, the rate at which the heat is dissipated must equal the rate at which it is introduced into the harbor waters. Since, however, transport and dissipation of the heat is a function of temperature, this equilibrium may not be reached before the heat has been mixed throughout the harbor and average harbor temperatures thus raised.

Close to the point of discharge, the transport of heat through mixing with the ambient water proceeds at a very high rate in comparison with the dissipation of heat through the naviface. In this area, the temperature increase will be much higher than that experienced by stations outside the direct influence of the plume.

A segmented mathematical model of New Haven Harbor was developed by Ebasco Services, Inc. (1971) to assess the effect of the generating station thermal load on average temperatures in New Haven Harbor. The Harbor was divided into 36 discrete segments (Figure 3-21) and an energy balance equation written for each segment. These equations assessed explicitly the effect upon the time and depth-averaged temperature of heat exchange across the air-water interface, mixing of the heat load within the harbor, and the direct input of heat from New Haven Harbor Station and the UI English Station (Figure 3-21). Exchange of heat with the Sound is not accounted for in the model: no heat is assumed to cross any of the external boundaries of the model, which include the southern boundaries of segments 33, 34, 35 and 36. This means that, for the model, all the heat discharged by the power plants must be dissipated to the atmosphere within the bounds of the model segments. In the natural system, some of the water which leaves the harbor on the ebb tide is carried away by currents in the Sound and does

Figure 3-21. EBASCO model segments (EBASCO, 1971). New Haven Harbor Ecological Studies Summary Report, 1979.

not return on the flood tide: the water which does not return carries away heat. The proportion of water that is flushed has not been studied for New Haven Harbor; however, the assumption used in the model, namely that all the heat returns with the flooding tide, maximizes the temperature increase in the harbor and is thus conservative.

A minimum flow condition that can occur during July and August and corresponding average meteorological conditions for these months were used as inputs to the model. Dispersion coefficients were determined by applying the model to predict the salinity distribution measured during July and August of 1963 (Duxbury, 1963); current speeds and directions were from the same source.

Figure 3-22 shows the full-depth tidal cycle average harbor temperature increase resulting from operation of the New Haven Harbor Generating Station at 100% capacity (heat load of 545×10^6 Kcal/hr) and operation of the UI English Station at 50% capacity (heat load of 170×10^6 Kcal/hr). The English Station is located on the Mill River and during operation discharges cooling water to model segment 5. The figure shows that the inner part of the harbor is subjected to an average temperature rise of about 0.8 F (0.4 C) with outlying areas about 0.5 F (0.3 C) above ambient temperature.

The mathematical model-predicted temperatures represent the average temperatures throughout the water column for each segment at a steady-state condition. For steady state to occur, the parameters affecting temperature, i.e., meteorology, freshwater flow, diffusion coefficients, and heat loads, must be constant for periods ranging from about two weeks to a month. In actuality, these parameters are continually varying and a steady-state condition does not occur. However, since Ebasco has chosen realistic worst-case conditions as non-varying inputs, and because the flushing of heat into the Sound is underestimated, the temperatures determined by the model can be considered to be conservatively high.

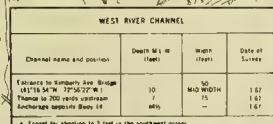


Figure 3-22. Full depth tidal cycle average water temperature increases (°F) (EBASCO, 1971). New Haven Harbor Ecological Studies Summary Report, 1979.

Hydrographic surveys of New Haven Harbor were conducted by Ebasco during May and September 1970 (Ebasco, 1971). The surveys consisted of releasing, at a known constant rate, a 30% solution of Rhodamine B dye at the generating station discharge location and measuring the resulting dye concentrations at the locations in the harbor shown in Figure 3-23. Full-depth-averaged dye concentrations were obtained for each survey location and related to temperature in the same manner as was done for the NAI thermal surveys (NAI, 1976). Tables 3-4 and 3-5 show the temperature increase for the generating station, converted from measured dye concentrations as an ebb slack, flood slack and tidal cycle average.

On a full-depth-average basis, Tables 3-4 and 3-5 show that only one survey station, namely E20, will be subjected to temperature increases of 1 F (0.6 C) or greater. A maximum full-depth-average temperature increase of 1.22 F (0.7 C) was recorded at survey station E20 at ebb slack during the EBASCO September survey. These temperature estimates do not take into account thermal decay due to heat loss to the atmosphere across the air-water interface. EBASCO also erected a non-steady-state model for thermal plume (EBASCO, 1971) which was in general agreement with the more accurate surveys and dye studies conducted post-operationally (NAI, 1976; 1977).

Continuous measurements of near-surface and near-bottom water temperatures were made at the Honeywell Water Quality Monitor from 1974 through 1977. Table 3-6 gives the mean annual near-surface and near-bottom temperatures for September to August, 1974-75, 1975-76, and 1976-77. During the first year of plant operation (September 1975 to August 1976), mean annual temperatures rose about 0.8 F over the preceding year. From September 1976 to August 1977, mean temperatures dropped to about 52.9 F, or about 1.6 F lower than in the preoperational year shown, in response to the record cold of that year. It can be seen from the Honeywell data that naturally occurring mean temperature fluctuations are greater than those which may occur as a result of the thermal load from the generating plant. Table 3-6 also shows that, on a yearly-

(Text continued on page 3-84)

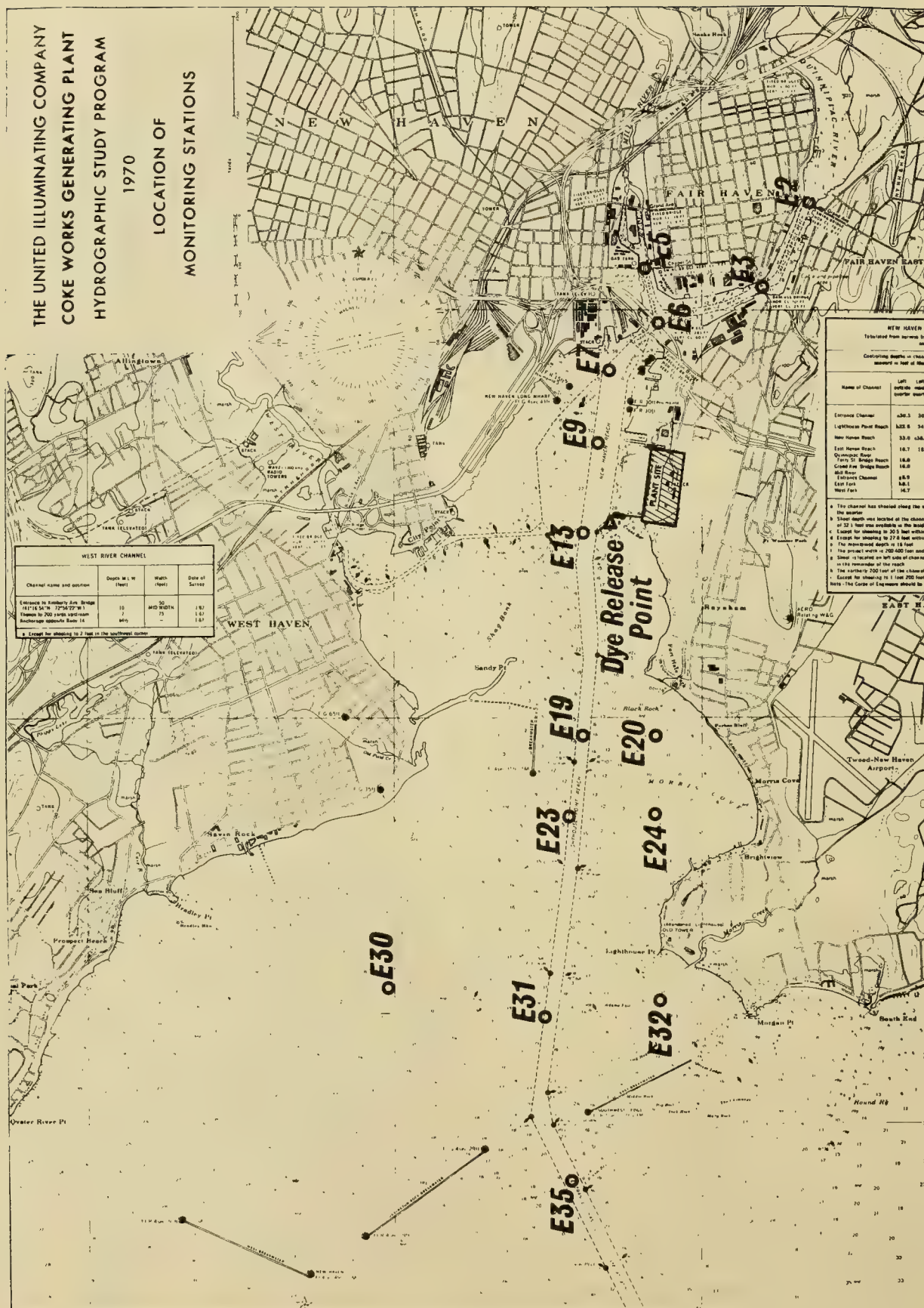


Figure 3-23. EBASCO dye study stations (EBASCO, 1971). New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 3-4. FULL DEPTH AVERAGE TEMPERATURE INCREASE, MAY, 1970
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT,
1979.

TEMPERATURE (F)

LOCATION	EBB	FLOOD	TIDAL AVERAGE
E 2	.20	.35	.28
E 3	.22	.32	.27
E 5	.26	.25	.26
E 6	.24	.30	.27
E 7	.30	.34	.32
E 9	.42	.35	.39
E 13	.60	.56	.58
E 19	.46	.45	.46
E 20	.98	.65	.82
E 23	.36	.24	.30
E 24	.52	.64	.58
E 30	.21	.10	.16
E 31	.23	.11	.17
E 32	.28	.22	.25
E 35	.15	.04	.10

TABLE 3-5. FULL DEPTH AVERAGE TEMPERATURE INCREASE, SEPTEMBER 1978.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

TEMPERATURE (F)

LOCATION	EBB	FLOOD	TIDAL AVERAGE
E 2	.13	.76	.45
E 3	.14	.58	.36
E 5	.51	.70	.61
E 6	.24	.44	.34
E 7	.35	.52	.44
E 9	.41	.18	.30
E 13	.44	.54	.49
E 19	.26	.22	.24
E 20	1.22	.20	.71
E 23	.28	.08	.18
E 24	.53	.14	.34
E 30	.02	.01	.02
E 31	.06	.02	.04
E 32	.27	.12	.20
E 35	.04	.00	.02

TABLE 3-6. SUMMARY OF HONEYWELL CONTINUOUS MEAN ANNUAL WATER TEMPERATURE DATA FOR PREOPERATIONAL AND POST-OPERATIONAL CONDITIONS.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

PERIOD	<u>NEAR SURFACE</u>		<u>NEAR BOTTOM</u>	
	$\bar{X}$	σ	$\bar{X}$	σ
<u>PREOPERATIONAL</u>				
Sept. 1974 to Aug. 1975	54.48 F	15.01	54.48 F	13.64
<u>POST-OPERATIONAL</u>				
Sept 1975 to Aug. 1976	55.27 F	13.82	55.19 F	13.75
Sept. 1976 to Aug. 1977	52.91 F	15.08	52.96 F	15.24

average basis, the temperature increase due to operation of the generating station is probably less than 1 F (0.6 C) at the water quality monitor.

The NAI thermal surveys conducted during July, August, and October 1976 give quantitative information about the extent of the generating station thermal plume. The results of the surveys conducted during October 13, 1976, are shown in Figures 3-24 through 3-27. At slack low water, a small plume is apparent near the discharge point (Figure 3-24). Its maximum surface temperature rise was about 5 F (2.8 C) above ambient. The percentage of the surface area of the inner harbor bounded by the 4 F ΔT isotherm is less than 0.1%. The 3, 2 and 1 F (1.7, 1.1 and .6 C) ΔT isotherms bound 0.4, 0.6, and 1 percent respectively of the inner harbor surface area. Cross-sectional data show the plume to have been a near surface feature (Figure 3-24). Temperatures representing ΔT 's of 3 to 5 F (1.7 - 2.8 C) occupied the upper 4 m of the water column. From 4 to 7 m, ΔT 's were 2 to 3 F. Below the 7 m depth, temperatures were at or very close to ambient.

At maximum flood tide, the plant's thermal plume was less concentrated, due to greater mixing with ambient waters (Figure 3-25). The temperature rise directly above the discharge point was about 3 F, with the 3 F ΔT isotherm enclosing less than 0.1% of the inner harbor surface area. The 1 to 2 F ΔT portion of the plume water was observed to curve across the navigation channel and up toward Long Wharf, with the 1 F ΔT isotherm enclosing 2.4% of the inner harbor area. The cross-sectional presentation shows the plume concentrated near the discharge, with dilution down to less than 1 F ΔT occurring only a short distance from the plume axis.

At high water slack (Figure 3-26), the maximum surface temperature increase was 2 F, but covered a very small surface area near the discharge (less than 0.1%). The 1 F ΔT isotherm covered 2.2% of the area of the inner harbor. Cross-sectional data show that the thermal plume intersected the bottom directly in front of the discharge. At

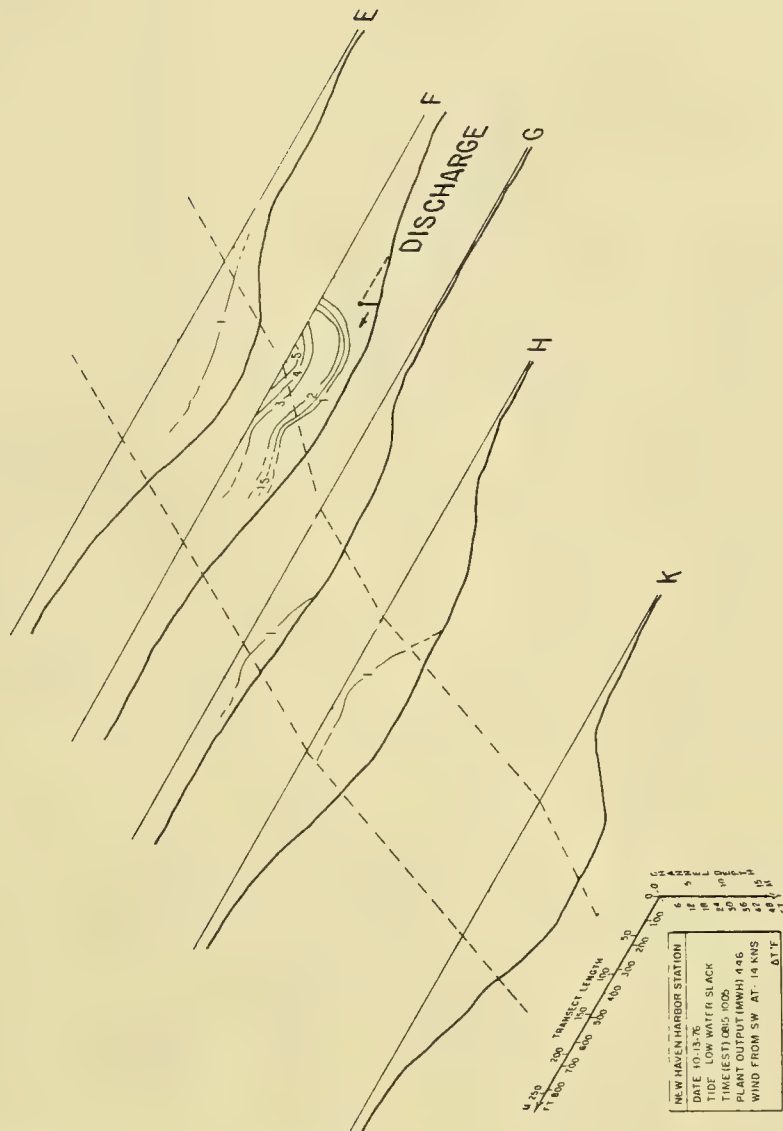
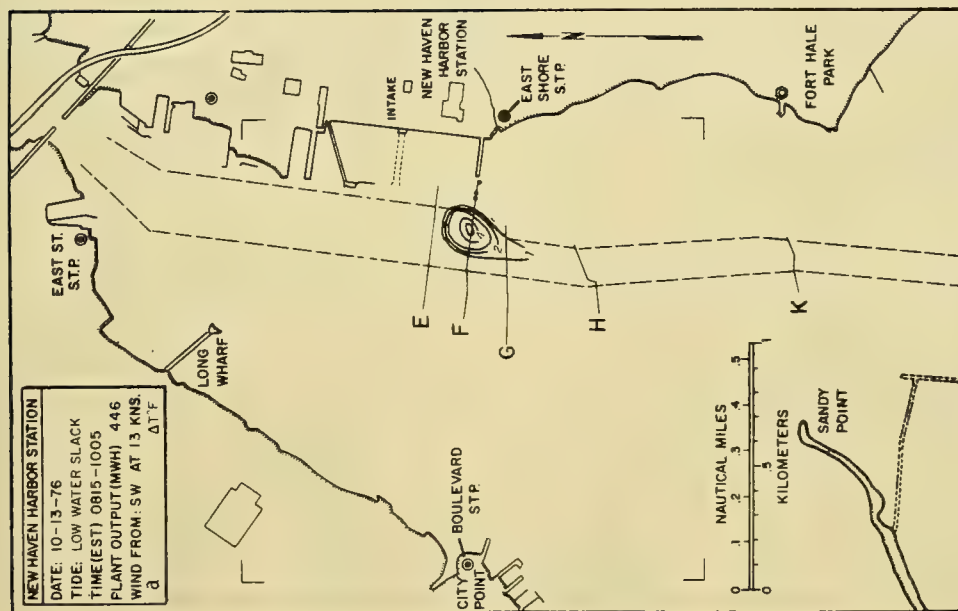


Figure 3-24. Isotherms ($\Delta t^{\circ}F$) from October 13, 1976, thermal survey at low water slack. New Haven Harbor Ecological Studies Summary Report, 1979.

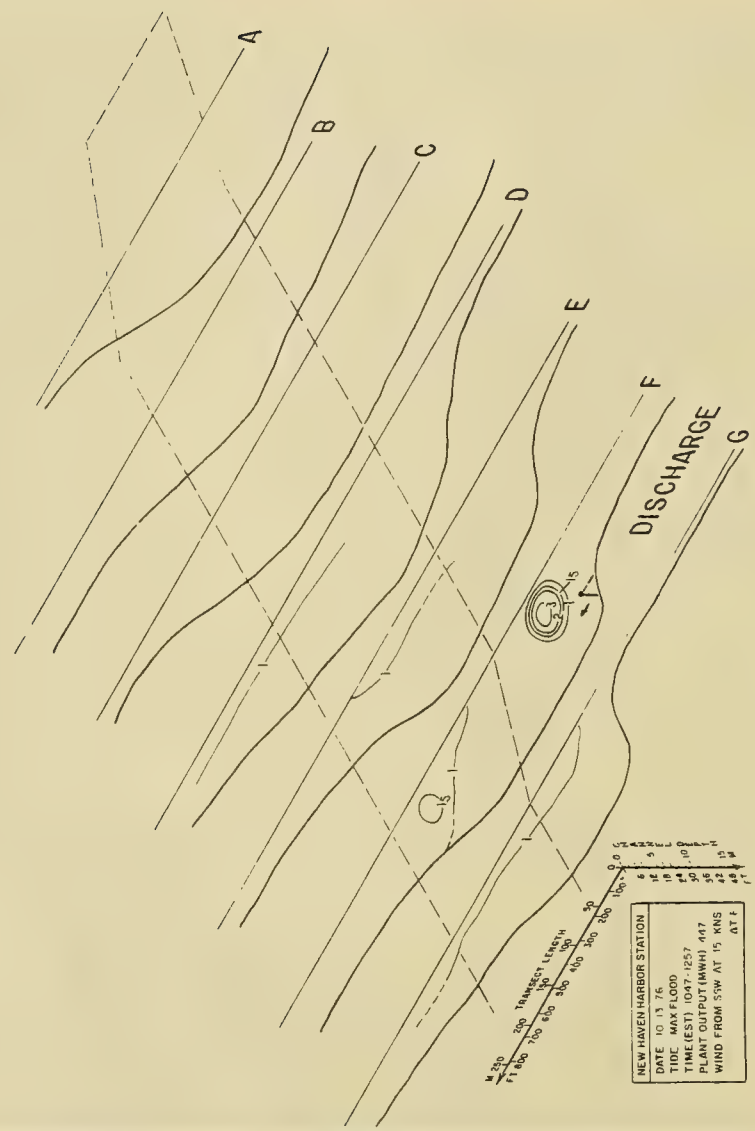
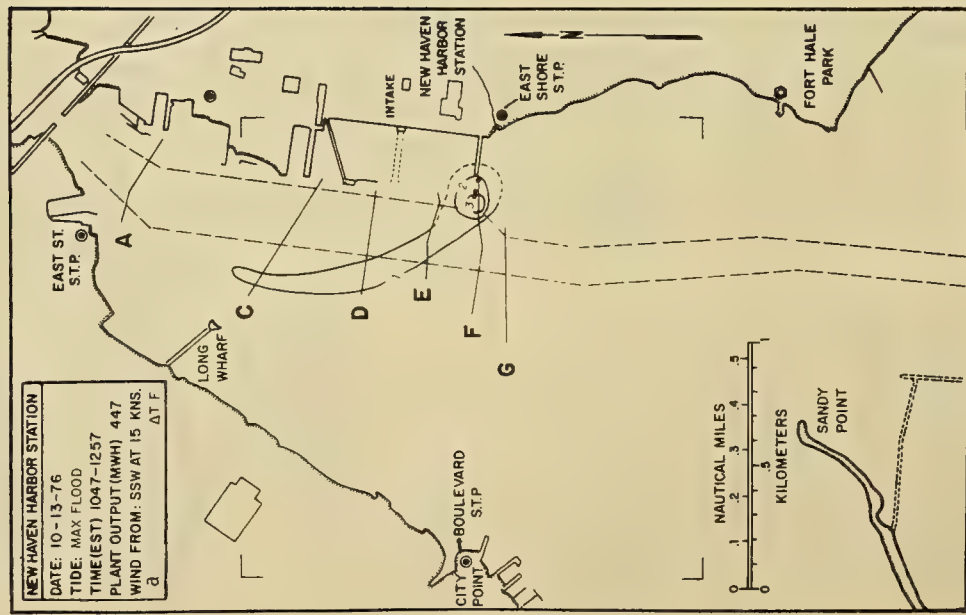


Figure 3-25. Isotherms ($\Delta t^{\circ}F$) from October 13, 1976, thermal survey during maximum flood current. New Haven Harbor Ecological Studies Summary Report, 1979.

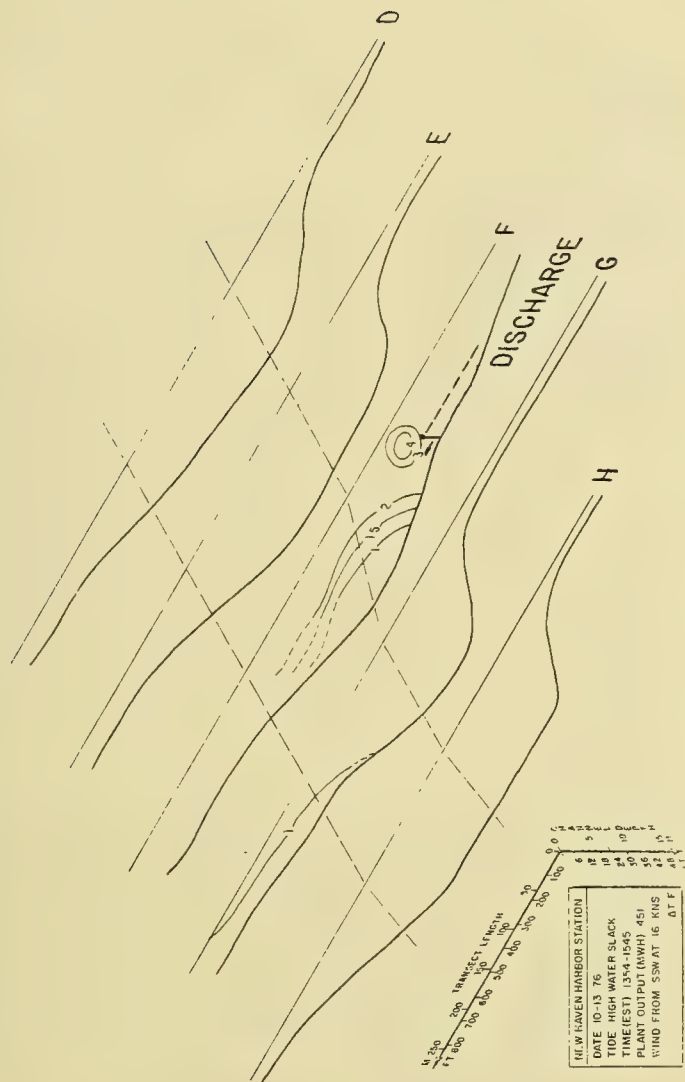
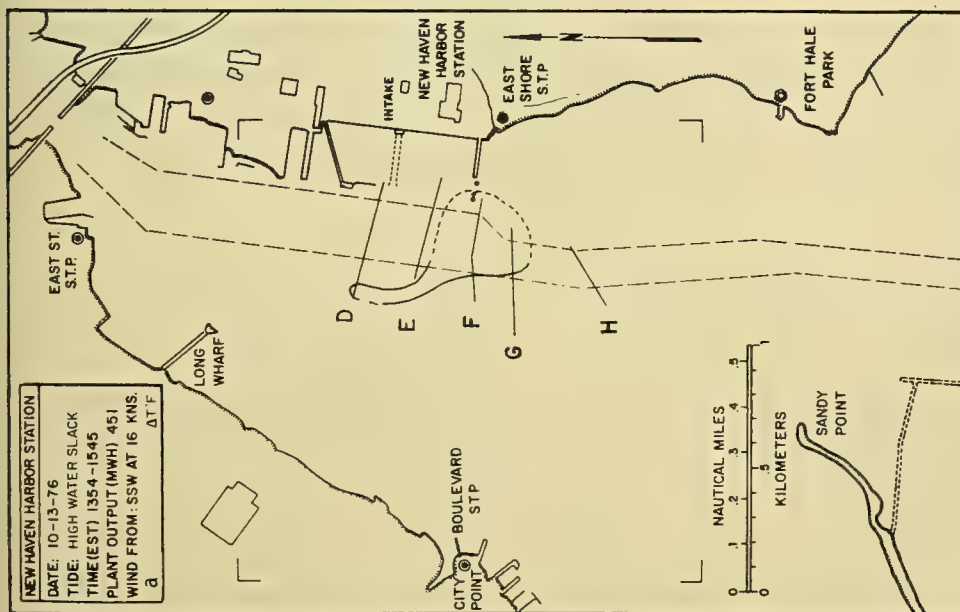


Figure 3-26. Isotherms ($\Delta t^{\circ}\text{F}$) from October 13, 1976, thermal survey at high water slack.
 New Haven Harbor Ecological Studies Summary Report, 1979.

this time the 1 F ΔT isotherm bounded 30.5% of the cross-sectional area of Transect F (Figure 3-26).

At maximum ebb, the plant's thermal plume had the greatest horizontal extent (Figure 3-27). Temperature rises of 4 F occurred above the discharge. Temperature increases of 1 to 2 F extended beyond Fort Hale Park. The area bounded by the 1 F ΔT isotherm is equal to 12.6% of the surface area of the inner harbor. Cross-sectional data show water with increased temperature of 2 to 3 F extending from surface to bottom in the water column at the transect just south of the discharge where the plume enters the main channel (Transect G, Figure 3-27). At this time there was no area in the main channel at Transect G which did not have a temperature rise of at least 1 to 2 F. Further south of the discharge point, the plume apparently thinned out and possibly formed a surface layer 1 to 2 m thick.

Generally, the NAI dye and thermal surveys showed that the percentage of the surface area of the inner harbor subjected to a temperature rise of 1 to 4 F was small. In each study, the area bounded by the 4 F ΔT isotherm was equal to or less than one-tenth of one percent of the total inner harbor area. The areas bounded by ΔT isotherms of 3 F ranged from zero to 0.4% in October and from 0.1% to 0.5% in August. A much larger area was bounded by the 2 F ΔT isotherm; the percentage affected ranged from less than 0.1% to 3% in October and from 0.5% to 5.5% in August. The percentage of surface area bounded by a ΔT of 1 F ranged between 0.7% and 12.6% in October and between 2.7% and 11.2% in August.

In October, the percentage of the cross-sectional area of Transect F bounded by the 4 F ΔT isotherm was zero during four of the eight tide phases studied, and it ranged to a maximum of 2.9% during low slack on October 13. For August, the range was between zero and 3.2%. The 3 F ΔT isotherm bounded up to 6.7% and 8.5% of Transect F in October and August, respectively. The area bounded by the 2 F ΔT isotherm ranged from 1.9% to 22.8% in October and from 10.4% to 20.6% in August. The areal extent of the 1 F ΔT contour was quite variable in October,

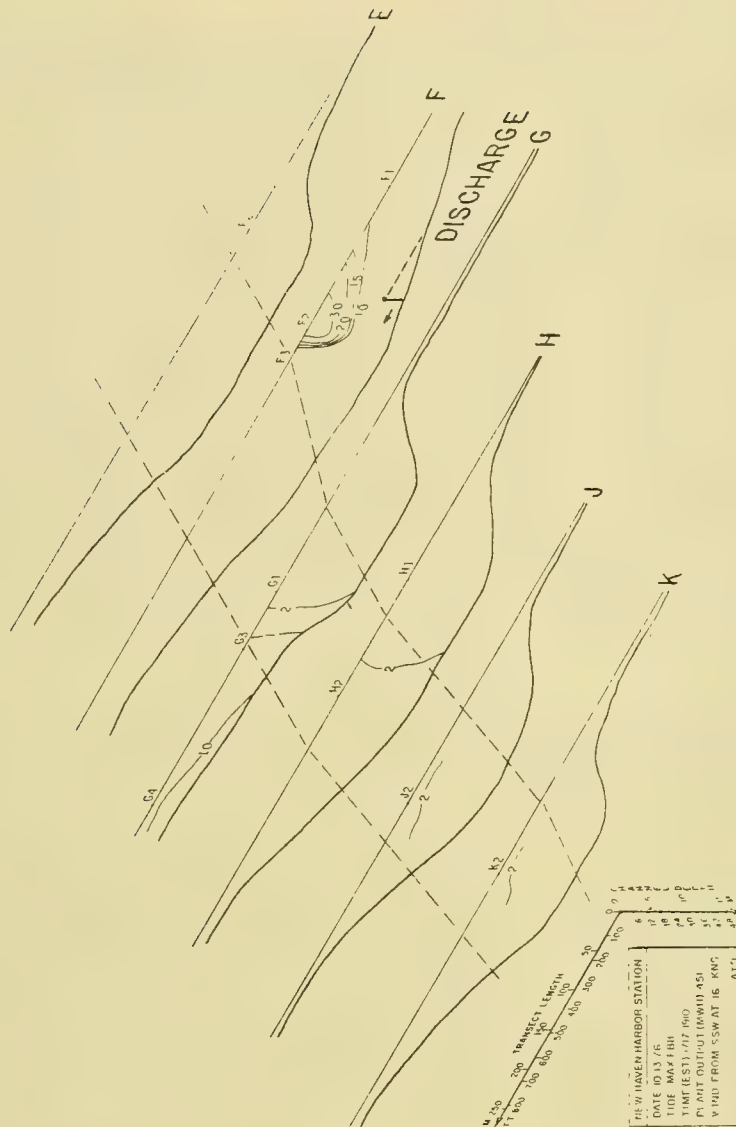
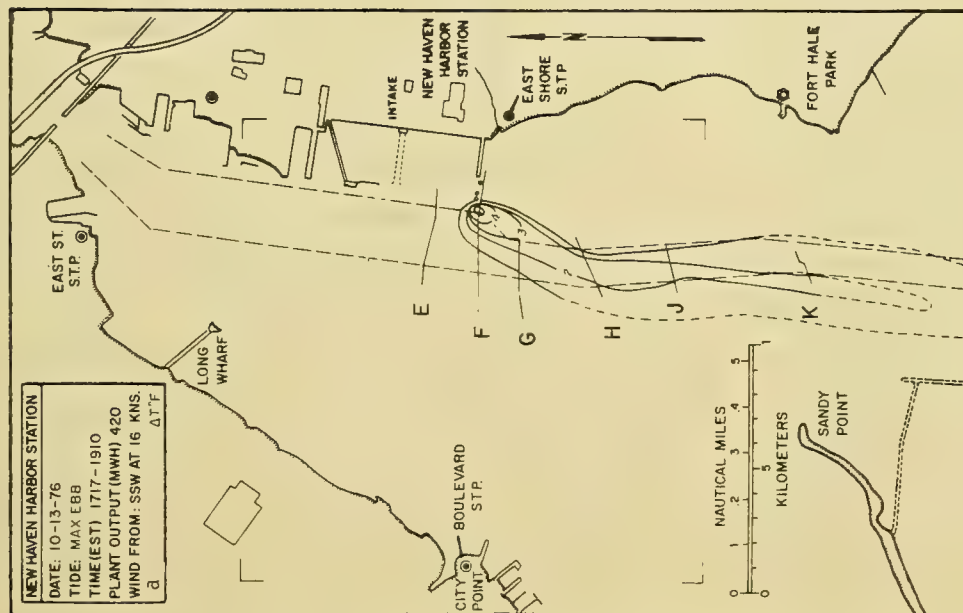


Figure 3-27. Isotherms ($\Delta t^{\circ}F$) from October 13, 1976, thermal survey during maximum ebb currents. New Haven Harbor Ecological Studies Summary Report, 1979.

ranging from 7.4% to 40.2%. August showed less variability; the range then was from 22.3% to 41.6% of the area of Transect F.

During 1976, NAI analyzed aerial infrared imagery and "ground truth" information to assess the extent of the generating station thermal plume and the magnitude of other thermal inputs to New Haven Harbor (NAI, 1976). These data covered the period of September 3 and 4. With the plant at or near full load, it was found that the 2 F ΔT isotherm encompassed approximately 2.3 to 5.5% of the inner harbor surface area at high slack and maximum ebb flow, respectively. The maximum surface temperature in the vicinity of the discharge was 74 F during low slack tide. This represented an increase of 4 F over adjacent surface water temperatures.

Increased surface water temperatures were observed in other areas of the harbor. Maximum surface temperatures from the UI English Station of 72 to 76 F (22.2-24.4 C) were observed in the Mill River. In the shoal areas along the western side of the harbor, solar radiation raised the temperature of the water above 74 F (23.3 C).

Thermal addition was not sufficient to cause fog or to significantly affect winter ice cover.

In summary, the thermal discharge from New Haven Harbor Generating Station:

1. raises full-depth tidal cycle average temperatures by less than 0.8 F in the inner part of the harbor and less than 0.5 F in outlying areas.
2. raises surface temperatures by a maximum of 4 F where the plume intersects the surface.
3. can occasionally cover the complete cross-sectional area of the navigation channel with water 1 to 2 F warmer than ambient.

Changes in Dissolved Oxygen Concentration

The solubility of oxygen in sea water is a function of temperature, salinity and pressure. Solubility decreases with increasing temperature and salinity, but increases with increasing pressure.

The New Haven Harbor Generating Station changes the oxygen solubility by mixing water properties at intake and increasing the temperature of the water by 15 F. The effect that the change in solubility has on the actual amount of dissolved oxygen contained in the harbor waters depends on the percent saturation of the discharged water and the pressure.⁺ When water with a percent saturation over 100% reaches depths where the pressure is not great enough to keep the oxygen dissolved, oxygen may bubble out and be lost to the atmosphere. The potential for this occurrence in New Haven Harbor can be demonstrated for winter conditions.

Table 3-7 gives the properties of a hypothetical water column which are typical of that at Station 4 during the winter. The dissolved oxygen content of the water was determined by assuming 100% saturation.

If the water column was quickly and completely mixed at the intake to the generating station, the water would have a temperature of 1.9 C, a salinity of 17.6 ppt, and a dissolved oxygen concentration of 12.2 mg/l. At the discharge, the temperature of the water would be 10.2 C. The solubility of oxygen in water of 10.2 C and 17.6 ppt is 6.87 ml/l (9.8 mg/l at 1 atm), thus the percent saturation of the discharge is 124%. The 12.2 mg/l of oxygen does not have a volume of 6.87 ml/l until it reaches a depth of 4 m below the surface, by which time it has been mixed with the ambient water in a ratio of approximately 3 to 1. Assuming that the ambient water in the region of the discharge has a salinity of 24 ppt, a temperature of 3 C, and is 100% saturated with dissolved oxygen (concentration of 11.3 mg/l), the plume water at the

⁺The percent saturation of oxygen in sea water is defined as one hundred times the observed concentration of dissolved oxygen divided by its solubility in water at the same temperature and salinity under a pressure of 1 atm.

TABLE 3-7. PROPERTIES OF A HYPOTHETICAL WATER COLUMN,
CHARACTERISTIC OF WINTER CONDITIONS. NEW
HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT,
1979.

DEPTH (M)	TEMPERATURE (°C)	SALINITY (%)	DISSOLVED OXYGEN (PPM)
SURFACE	0.3	2.9	13.8
1	0.8	6.2	13.6
2	1.3	10.7	12.8
3	1.7	22.6	11.7
4	3.3	23.2	11.2
5	3.0	23.5	11.3
6	2.5	23.5	11.4
7	2.5	23.5	11.4

4 m depth has a salinity of 22.4 ppt, a temperature of 4.8 C, and a dissolved oxygen concentration of 11.5 mg/l. The solubility of oxygen in water with these properties is 7.6 ml/l (10.9 mg/l at 1 atm). This means that the plume water is 106% saturated at a depth of 4 m. At 4 m the volume of 11.5 mg/l of oxygen is less than the saturation value, so there is no tendency for the oxygen to come out of solution. When the plume reaches the surface it has been diluted by an additional factor of approximately 25 to 1. Assuming that the last 4 m of the water column has a salinity of 10 ppt, a temperature of 1 C and is 100% saturated, the discharge water would have a salinity of 19.9 ppt, a temperature of 4 C, and a dissolved oxygen concentration of 11.8 mg/l when it reaches the surface. With these properties, the discharge water at the Harbor surface is 105% saturated with oxygen and could potentially lose 0.4 mg/l of oxygen to the atmosphere.

The potential for this loss of oxygen to occur in water which has passed through power plants has been recognized and studied at other locations. Jacobson (1976) studied the oxygen balance in the condenser-cooling water system of the Connecticut Yankee Plant and found that oxygen concentrations decreased throughout the cooling system (which unlike the New Haven Harbor Generating Station system included contact with the atmosphere before discharge into the river) when intake waters became supersaturated upon the addition of heat. These losses ranged between 0.9 and 1.3 mg/l and usually occurred at ambient water temperatures below 6 C and at ambient dissolved oxygen concentrations above 11.8 mg/l. Dissolved oxygen concentrations remained virtually unchanged after passage through the condenser when percent oxygen saturations in the heated water were below 100%. Adams (1969), studying two tidewater power plants in California, noted supersaturation of oxygen in the discharge waters but found no changes in dissolved oxygen concentrations.

The situation that appears to exist in New Haven Harbor is that the generating station has little effect on the amount of oxygen dissolved in the Harbor waters. During the summer months, the harbor is

undersaturated with regard to oxygen. The generating station will raise the percent saturation by approximately 17% at discharge. Usually this will be reduced to less than 7% by mixing with the ambient water before the discharge plume reaches the surface. Since the inner harbor percent saturations are generally below 70% from June through August, an increase of even 17% would not create a situation where oxygen could be lost by the Harbor waters.

The example test case shows that, during the winter the generating station could cause oxygen supersaturation in the discharge plume, and that in the example there is a potential to lose 0.4 mg/l of oxygen to the atmosphere. Whether oxygen is actually lost to the atmosphere in the Harbor, as occurred in the study by Jacobson (1976), or whether there is supersaturation without any loss of oxygen, such as was observed by Adams (1969), cannot be determined from the available data.

Table 3-8 shows the percent of oxygen saturation at the surface at Stations 4, 8, 9, 11 and 16 for January through December 1976 during ebb tide. It can be seen that supersaturation of the surface waters is common throughout the year at Station 16 and at all stations during the winter. These high values are probably due to the rapid natural mixing of water properties that characterizes this and most other estuaries. Station 8, which is most likely to represent plume water, does not show unusually high values of percent saturation. Examination of the dissolved oxygen concentrations observed at Station 8 during 1976 reveals that they were not low in comparison to Stations 4 and 9.

In summary, the New Haven Harbor Generating Station has no effect on dissolved oxygen concentrations in the harbor during the summer months when the percent saturation is well below 100%. During the winter, when percent oxygen saturation is near or greater than 100%, the station has the potential for driving a small amount (less than 1 mg/l) of oxygen out of solution by heating and mixing of waters; however, natural estuarine mixing in the harbor causes a great deal of

TABLE 3-8. PERCENT SATURATION OF DISSOLVED OXYGEN AT THE SURFACE DURING 1976 AT EBB TIDE. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	Sta. 4	Sta. 9	Sta. 8	Sta. 11	Sta. 16
January		84	98		
February	116	120	123	122	128
March		86	75	80	110
April	119	137	125	131	135
May		94	91	93	98
June	42	43	76	88	114
July	32	54	70	101	127
August	49	70	69	83	100
September	56	101	89	86	126
October	86	98	96	88	97
November	91	98	101	101	102
December	98	103	98	127	104

supersaturation during this time of year. In at least one study (Adams, 1969), oxygen supersaturation in thermal discharge has been found to occur without the loss of oxygen to the atmosphere. Oxygen removal can only occur when ambient oxygen concentrations are relatively high, and thus has no adverse ecological impact.

Increased Turbidity

The physical model studies conducted by the University of Florida (UOF, 1972) predicted extensive scour of the bottom during the startup of operations at the generating plant if preventive measures were not taken. In response to this prediction, UI installed a protective rip-rap on the bottom at the end of the discharge pipe. Figure 3-28 shows the protective rip-rap and selected depth contours from a bathymetric survey conducted by the Army Corps of Engineers in January 1978; Figure 3-29 shows selected contours from a survey conducted in the spring of 1974 before the generating station began operations. From these two figures it can be seen that the dredging done when the discharge pipe was installed changed the bottom in the vicinity of the discharge. Figure 3-28 shows a short trench or hole that begins at the westerly end of the rip-rap. Though this area may have been dug out during the dredging operations, it may also have been scoured out by the discharged water. It was shown earlier (p. 69) that the plume travels further horizontally before rising to the surface than was found in the physical model. This extended horizontal reach of the discharged water may indicate that the area of the protective rip-rap is less than what is needed to prevent scour of the bottom. If the area of the bottom that could be scoured is defined by the 38 ft (11.6 m) depth contour, then Figure 3-28 shows 2327 m² to be affected. A sediment trap study conducted by Battelle (1971) shows the rate of deposition in this area to be about 1.5 cm/mo. If the generating station was taken off line for a week the amount of sediment which potentially could be resuspended by the discharge would be approximately:

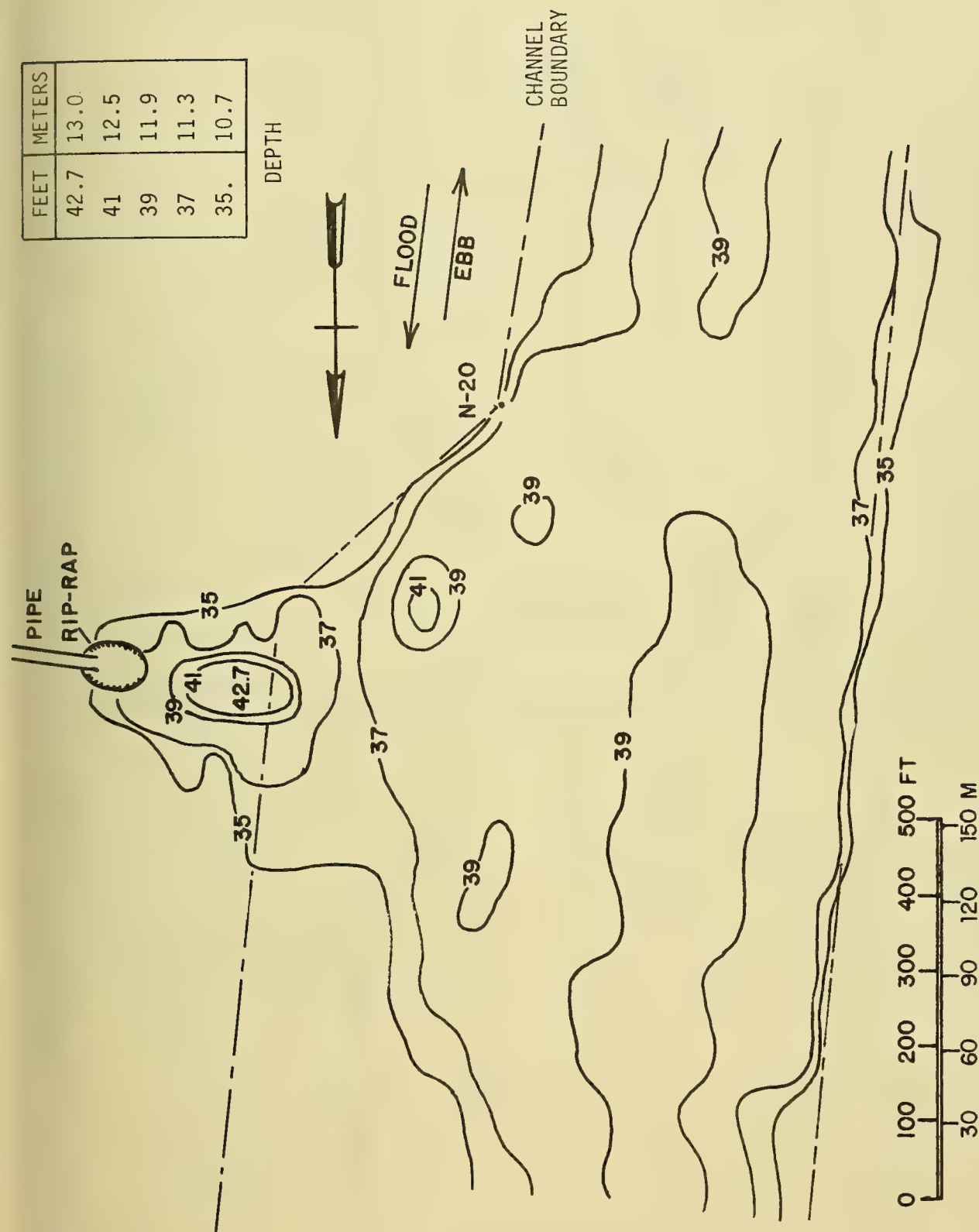


Figure 3-28. Post-operational bathymetric survey of discharge area (USACE, January 1978; unpublished). New Haven Harbor Ecological Studies Summary Report, 1979.

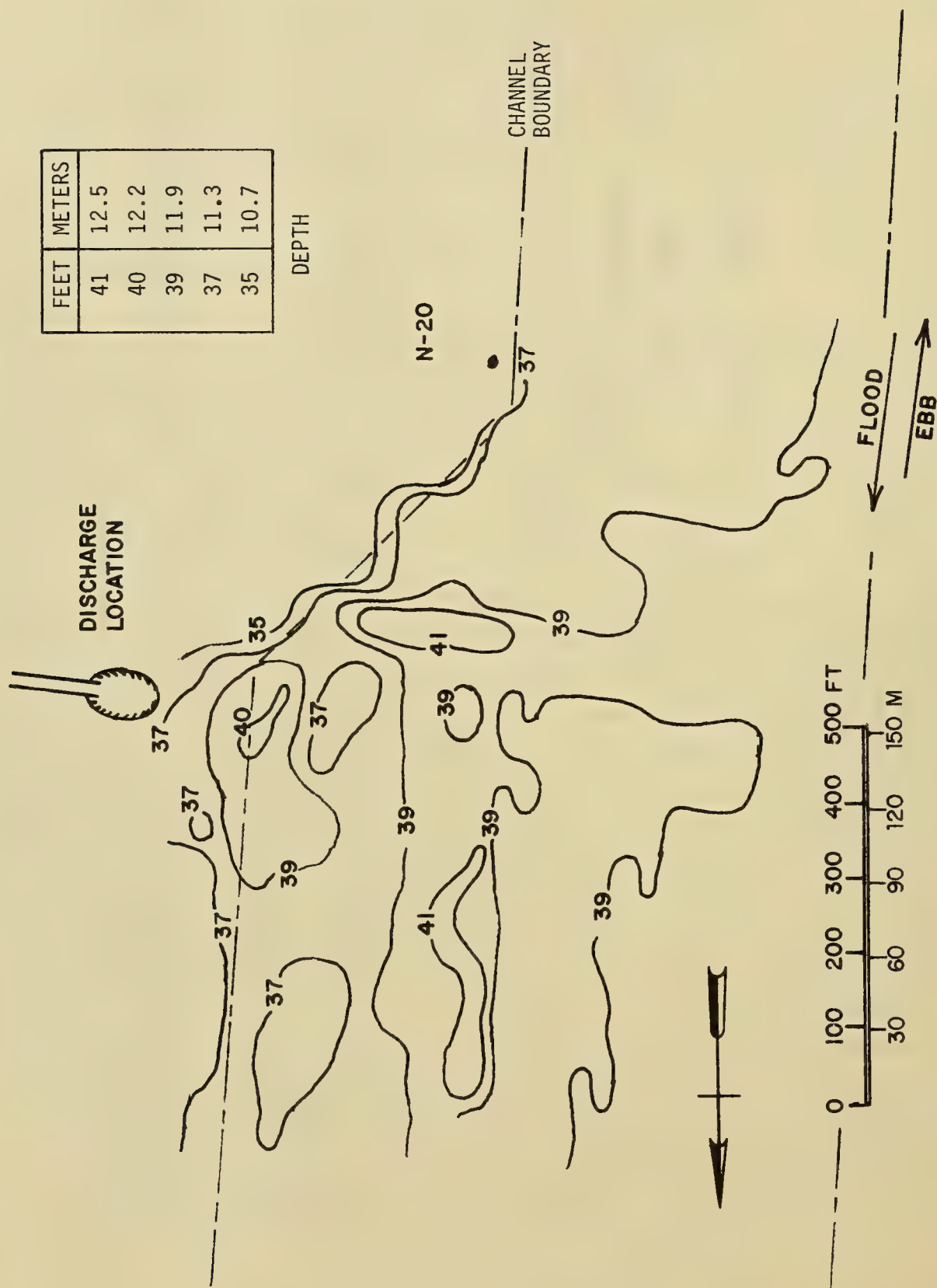


Figure 3-29. Preoperational bathymetric survey of discharge area (USACE, May 1974; unpublished). New Haven Harbor Ecological Studies Summary Report, 1979.

$$(2327 \text{ m}^2) (1.5 \frac{\text{cm}}{\text{mo}}) (\frac{1 \text{ mo}}{4 \text{ wks}}) = 8.7 \text{ m}^3 (11.6 \text{ yd}^3)$$

The rate at which the sediment could be scoured out (and the resultant turbidity) cannot be easily determined.

Analysis of measurements of water transparency (or depth of visibility readings from Secchi disc measurements) and turbidity show no distinct patterns relative to plant operations.

Summary of Impacts

In summary, the impacts of New Haven Harbor Station operations appear to be slight. Minor alterations of local current patterns, creation of 8-cm waves, and small, localized increases in turbidity near the discharge during start-up after prolonged down-time probably occur, though none of these have been measured. Dissolved oxygen concentrations could be reduced slightly (<17%) when saturation is near or greater than 100% -- in effect, when minor alteration of DO is ecologically unimportant. Monitoring programs have detected no change in DO concentrations attributable to New Haven Harbor Station operations.

The only impact quantitatively measured was the establishment of a thermal plume which: 1) is detectable ($\Delta t \geq 1^\circ\text{F}$) over a maximum of 42% of the inner harbor surface, 2) creates a small "boil" where surface temperatures may be elevated by as much as 4 F over ambient, 3) occasionally covers the complete cross-sectional area of the navigation channel with water 1-2 F warmer than ambient.

The New Haven Harbor Station discharge may raise average temperatures in the inner and outer harbors by less than 0.8 F and 0.5 F, respectively. This increase is less than that induced by annual climatological variation.

Overall, the impacts of New Haven Harbor Station operations on New Haven Harbor hydrography are small and lie well within the range of phenomena in nature. From these data it would appear to be highly unlikely that the impacts of the New Haven Harbor Station would have any significant, adverse environmental effects.

LITERATURE CITED -- HYDROGRAPHIC

- Adams, J. R. 1969. Thermal power, aquatic life and kilowatts on the Pacific coast. Nucl. News. September:75-79.
- Battelle Memorial Institute. 1971. Environmental monitoring program: Service program, marine ecology and biology, New Haven Harbor, Connecticut, May-October 1971. Prepared for United Illuminating Company, New Haven, Connecticut.
- Battelle Columbus Laboratories. 1977. A monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area: Annual report of ecological and hydrographic studies 1976. Prepared for Northeast Utilities Service Company, Berlin, Connecticut.
- Bokuniewicz, Henry J. 1976. Estuarine sediment flux evaluated in Long Island Sound. Ph.D. dissertation, Yale University. 170 pp.
- _____, J. Gebert and R. B. Gordon. 1975. Recent sedimentation in Long Island Sound. 7th Annual Long Island Sound Conference, City University of New York, New York, New York.
- Bokuniewicz, Henry J., R. B. Gordon and C. C. Pilbeam. 1974. Circulation and sedimentation in central Long Island Sound. (ABS) Trans. Am. Geophys. Union. Vol. 5. p. 280.
- Bowman, M. J. 1976. Pollution predicted model of Long Island Sound. IN: Proceedings of Civil Engineering in the Oceans/III, Newark, Delaware, 9-13 June 1975. American Society of Civil Engineers, New York. pp. 1084-1103.
- _____. 1977. Nutrient distributions and transport in Long Island Sound. Estuarine and Coastal Marine Science. 5:531-548.
- Connecticut Department of Environmental Protection - Water Compliance Unit. 1977. Connecticut water quality standards and classifications. 90 pp.
- Duxbury, Alyn C. 1963. A hydrographic survey of New Haven Harbor, 1962-1963. Yale University.
- EBASCO Services, Inc. 1971a. Environmental Report: Coke Works Site, June 1971. Prepared for The United Illuminating Company, New Haven, Connecticut.
- _____. 1971b. 400 MW Coke Works Generating Plant: effect of heated cooling water discharge on the temperature distribution of New Haven Harbor. Prepared for The United Illuminating Company, New Haven, Connecticut.

- Environmental Protection Agency. 1971. Report on the water quality of Long Island Sound. EPA Water Quality Office. CWT-10-29.
- Federal Water Pollution Control Administration. 1969. Report on the water quality of Long Island Sound.
- Federal Water Quality Administration. 1970. New Haven Harbor shellfish resource and water quality. U.S. Dept. of Interior, Northeast Region, Needham Heights, Mass. 22 pp.
- Fisher, J. B. 1974. History of the Mill River. (unpublished) mimeographed.
- Florida Engineering and Industrial Experiment Station, Dept. of Coastal and Oceanographic Engineering. 1972. Buoyant jet discharge model study for Coke Works power plant, New Haven Harbor, Connecticut.
- Garvine, R. W. and J. D. Monk. 1974. Frontal structure of a river plume. J. Geophys. Res. 79:2251-2273.
- Goodkind, O'Day-Fay, Spofford and Thorndike. 1970a. Summary and recommendations of reports upon facilities for secondary treatment of sewage and industrial waste waters. Report No. 3. Prepared for the City of New Haven Department of Public Works.
- _____. 1970b. Report upon tidal studies of New Haven Harbor and New Haven thermal imagery. Prepared for the City of New Haven Department of Public Works. 3 volumes.
- Gordon, R. B. 1973. Turbidity due to dredge operations at the Coke Works site, New Haven Harbor, Connecticut. Department of Geology and Geophysics, Yale University, New Haven, Connecticut.
- Hardy, C. D. 1972a. Hydrographic data report: Long Island Sound, 1970, Part II. Mar. Sci. Res. Cent., Tech. Rept. No. 13. 20 pp.
- _____. 1972b. Movement and quality of Long Island Sound waters, 1971. Mar. Sci. Res. Cent., Tech. Rept. No. 17. 64 pp.
- _____ and P. K. Weyl. 1970. Hydrographic data report: Long Island Sound 1970. Part I. Mar. Sci. Cent., Tech. Rept. No. 6. 96 pp.
- _____. 1971. Distribution of dissolved oxygen in the waters of western Long Island Sound. Mar. Sci. Res. Cent., Tech. Rept. No. 11. 37 pp.
- Jacobson, P. M. 1976. Oxygen balance in the condenser-cooling water system of the Connecticut Yankee Plant. IN: The Connecticut River Ecological Study -- The impact of a nuclear power plant. D. Merriman and L. M. Thorpe (eds.). American Fisheries Society. Monograph No. 1. pp. 35-38.

- Jay, D. A. and M. J. Bowman. 1975. The physical oceanography and water quality of New York Harbor and western Long Island Sound. Mar. Sci. Res. Ctr. SUNY/SB Tech. Rpt. Ser. No. 23. 71 pp.
- Lawler, Matusky and Skelly Engineers. 1975a. Norwalk Harbor Station, Thermal Plume Studies. Prepared for Connecticut Light and Power Company, Berlin, Connecticut.
- _____. 1975b. Middletown Station, Thermal Plume Studies. Prepared for the Hartford Electric Light Company, Berlin, Connecticut.
- _____. 1975c. Devon Station, Thermal Plume Studies. Prepared for Connecticut Light and Power Company, Berlin, Connecticut.
- _____. 1976. Montville Station, Thermal Plume Studies. Prepared for Connecticut Light and Power Company, Berlin, Connecticut.
- Long Island Sound Regional Study. 1973. Sources and movements of water. An interim report. New England River Basins Commission, New Haven, Connecticut. 45 pp.
- _____. 1975. People and the Sound, power and environment. New England River Basins Commission. New Haven, Connecticut. 83 pp.
- National Academy of Sciences. 1977. Estuaries, geophysics and the environment. National Academy of Sciences, Washington, D. C. 127 pp.
- National Oceanic and Atmospheric Administration -- National Ocean Survey. 1977. Tide tables 1977, high and low water predictions, east coast of North and South America. pp. 212.
- New York Ocean Science Laboratory. 1974. Preoperational ecological monitoring program of the marine environs at the Long Island Lighting Company (LILCO) Nuclear Power Generating Facility, Shoreham, Long Island, New York. Volume I: Physical Oceanography and chemical oceanography.
- Normandeau Associates, Inc. 1971a. A bathythermographic survey of the receiving waters adjacent to the English Generating Station, New Haven, Connecticut. July 1971. Prepared for The United Illuminating Company, New Haven, Connecticut.
- _____. 1971b. Report on bacteriological, chemical and physical analyses of bottom sediments at the Coke Works site, New Haven Harbor, Connecticut. Prepared for The United Illuminating Company, New Haven, Connecticut. Draft.

- _____. 1972. Addendum 12 of environmental report: Coke Works site, June 1971, Marine Sediments, New Haven Harbor, Connecticut. Results of analyses and proposals for dredge spoil disposal. Prepared for The United Illuminating Company, New Haven, Connecticut.
- _____. 1973a. Coke Works Ecological Monitoring Studies, New Haven Connecticut. Annual Report, May 1971-March 1972.
- _____. 1973b. Bridgeport Harbor Ecological Studies, 1971-1972. Biological and hydrographic study reports. 296 pp.
- _____. 1974a. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report, May 1972-March 1973.
- _____. 1974b. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Interim Report, May-December 1973.
- _____. 1974c. Possible effects of thermal discharge from the English Generating Station on the ecology of New Haven Harbor, Connecticut.
- _____. 1974d. Stamford Harbor Ecological Studies, Stamford, Connecticut. Prepared for Northeast Utilities Service Company, Final Report.
- _____. 1974e. Supplementary research on the effects of thermal discharge from the English Generating Station on the ecology of Grand Avenue Reach, New Haven Harbor, Connecticut.
- _____. 1975a. New Haven Harbor Station Ecological Monitoring Studies, New Haven, Connecticut. Annual Report, January-December 1974.
- _____. 1975b. Ecological studies conducted at selected sites in New Haven Harbor, Connecticut. Prepared for the City of New Haven. 103 pp.
- _____. 1976a. New Haven Harbor Station Ecological Monitoring Studies, New Haven, Connecticut. Annual Report, January-December 1975.
- _____. 1976b. New Haven Harbor thermal regime during operation of the New Haven Harbor Station, September 3, 1975.
- _____. 1977a. New Haven Harbor Station Ecological Monitoring Studies, New Haven, Connecticut. Annual Report, January-December 1976.
- _____. 1977b. Thermal surveys of New Haven Harbor, Summer and Fall 1976.

- _____. 1978a. New Haven Harbor Station Ecological Monitoring Studies, New Haven, Connecticut. Annual Report, January-October 1977.
- Officer, Charles B. 1977. Longitudinal circulation and mixing relations in estuaries. pp. 13-21 IN: National Academy of Science, Estuaries, Geophysics and the Environment. Washington, D. C. 127 pp.
- Pritchard, Donald W. 1967. What is an estuary: physical viewpoint. pp. 3-5 IN: George H. Lauff (ed.). Estuaries. Amer. Assoc. Advancement of Science, Washington, D. C. Publ. No. 83. 757 pp.
- Quirk, Lawler and Matusky Engineers. 1969. New Haven Harbor: effect of increased waste treatment and outfall location on water quality. Prepared for State of Connecticut Water Resources Commission.
- Raytheon Company. 1970a. New Haven Harbor plankton survey, April-May 1970.
- _____. 1970b. New Haven Harbor Ecological Survey, Data Report, June-November 1970. Prepared for The United Illuminating Company, New Haven, Connecticut. 179 pp.
- _____. 1971. New Haven Harbor Ecological Survey, Data Report, December 1970-April 1971. Prepared for The United Illuminating Company, New Haven, Connecticut.
- Reid, R. N., A. B. Frame and A. F. Drexler. 1976. Environmental baseline studies in Long Island 1972-1975. National Marine Fisheries Service, NOAA, Sandy Hook, New Jersey.
- Riley, G. A. 1952. Hydrography of Long Island and Block Island Sounds. Bull. Bingham. Oceanogr. Coll. 13. pp. 5-39.
- _____. 1956. Review of the oceanography of Long Island Sound. Deep Sea Research Supplement. 3:224-238.
- _____. and S. A. M. Conover. 1956. Oceanography of Long Island Sound, 1952-1954. III: Chemical oceanography. Bulletin of the Bingham Oceanogr. Collec. 15. pp. 47-61.
- Riley, G. A. 1959. Oceanography of Long Island Sound, 1954-1955. Bulletin of the Bingham Oceanographic Collec. 17. pp. 9-29.
- Stone and Webster. 1972. Temperature prediction model for Long Island Sound. The Long Island Sound Study Group.
- SUNY, Marine Science Research Center. 1970. Biological Effects of thermal pollution, Northport, New York. Mar. Sci. Res. Ctr., SUNY Tech. Rept. No. 3. 107 pp.

- United Illuminating Company. 1970. The United Illuminating Company Thermal Discharge.
- University of Florida. 1972. Buoyant jet discharge model study for Coke Works power plant, New Haven Harbor, Connecticut. DCOE, FEIES, University of Florida.
- U.S. Army Corps of Engineers. 1973a. Environmental statement, Coke Works Electric Generating Plant, New Haven Harbor, Connecticut.
- _____. 1973b. Maintenance dredging, New Haven Harbor, Connecticut. Final Environmental Statement.
- U.S. Coast Guard. Oil spill records and pollution cases log book. U.S. Coast Guard New Haven Group. Unpublished data.
- U.S. Geological Survey, Water Resources Division. 1971. 1970 Water Resource Data for Connecticut. U.S. Geological Survey Water Data Report CT-70-1.
- _____. 1972. 1971 Water Resource Data for Connecticut. U.S. Geological Survey Water Data Report CT-71-1.
- _____. 1973. 1972 Water Resource Data for Connecticut. U.S. Geological Survey Water Data Report CT-72-1.
- _____. 1974. 1973 Water Resource Data for Connecticut. U.S. Geological Survey Water Data Report CT-73-1.
- _____. 1975. 1974 Water Resource Data for Connecticut. U.S. Geological Survey Water Data Report CT-74-1.
- _____. 1976. 1975 Water Resource Data for Connecticut. U.S. Geological Survey Water Data Report CT-75-1.
- _____. 1977. 1976 Water Resource Data for Connecticut. U.S. Geological Survey Water Data Report CT-75-1.
- Weyl, P. K. 1971. Temperature distribution of the heated effluent from the Northport Power Station (LILCO) in Long Island Sound. Tech. Rept. No. 10, Marine Science Research Center, SUNY at Stony Brook, New York. 25 pp.
- Wilson, R. E. 1976. Gravitational circulation in Long Island Sound. Estuarine and Coastal Marine Science. 4:443-453.

NEW HAVEN HARBOR STATION
ECOLOGICAL STUDIES
SUMMARY REPOT, 1979

4.0 PLANKTON

By Stephen A. Grabe, Doreen S. Newhouse,
David N. Pease, and Neil B. Savage
Normandeau Associates, Inc.
Bedford, N. H.

TABLE OF CONTENTS

	PAGE
INTRODUCTION.	4-1
METHODS AND MATERIALS	4-4
Phytoplankton	4-4
Zooplankton	4-6
Ichthyoplankton	4-8
CHARACTERIZATION OF THE NEW HAVEN HARBOR PLANKTON COMMUNITY . .	4-10
Phytoplankton	4-10
Zooplankton	4-28
Ichthyoplankton	4-49
Selected Species.	4-59
Analysis of Impacts	4-73
LITERATURE CITED -- PLANKTON.	4-82
APPENDIX.	4-86

LIST OF FIGURES

	PAGE
4-1. Phytoplankton, primary productivity and chlorophyll <i>a</i> samples collected from May 1971 to October 1977.	4-5
4-2. Monthly average chlorophyll <i>a</i> concentration (mg/m^3), standard deviation and range for Stations 3, 8, 18 and 20 on ebb tide; May 1971 through October 1977.	4-11
4-3. Monthly chlorophyll <i>a</i> concentrations (mg/m^3) at Stations 3, 8, 18 and 20 on ebb and flood tide; May 1971 through October 1977.	4-12
4-4. Total phytoplankton abundance (cells/liter) at Stations 3, 8 and 20 on ebb and flood tide; May 1974 through October 1977	4-14
4-5. Abundance (cells/liter) of <i>Skeletonema costatum</i> at Stations 3, 8 and 20; May 1974 through October 1977.	4-18
4-6. Abundance (cells/liter) of <i>Cyclotella</i> spp., <i>Thalassiosira rotula</i> and <i>Thalassiosira</i> spp. at Stations 3, 8 and 20; May 1974 through October 1977.	4-20
4-7. Abundance (cells/liter) of <i>Thalassiosira pseudonana</i> at Stations 3, 8 and 20; May 1974 through October 1977	4-21
4-8. Abundance (cells/liter) of <i>Thalassionema nitzschoides</i> at Stations 3, 8 and 20; May 1974 through October 1977	4-22
4-9. Abundance (cells/liter) of <i>Leptocylindrus minimus</i> at Stations 3, 8 and 20; May 1974 through October 1977	4-24
4-10. Abundance (cells/liter) of <i>Heterocapsa triquetra</i> at Stations 3, 8 and 20; January through October 1977	4-25
4-11. Abundance (cells/liter) of Cryptophyceae at Stations 3, 8 and 20; May 1974 through October 1977	4-27

- 4-12. Total zooplankton ($\#/m^3$) at Stations 3, 8 and 20 on ebb and flood tide; July 1973 through October 1977. . . . 4-31
- 4-13. Total zooplankton ($\#/m^3$) at Stations 3, 8 and 20 on surface and bottom (tides combined); July 1973 through October 1977. 4-32
- 4-14. Numbers per cubic meter of total zooplankton organisms and *Acartia* spp. taken with a No. 10 net [333 μm at Millstone] at a) New Haven Harbor, Stations 8 and 11 averaged, 1976; b) Niantic Bay, Millstone Stations 5 and 8 averaged, 1973-1976; c) Block Island Sound, 1949. . 4-34
- 4-15. Relative percentages of important copepod species from a) Long Island Sound, March 1952 to June 1953 (from Deevey, 1956); b) Millstone Units I and II discharge, 1976 and 1977 [333 μm net (from Battelle, 1978)]. . . . 4-35
- 4-16. Abundance ($\#/m^3$) of *Acartia hudsonica* and *Acartia tonsa* at Stations 3, 8 and 20; July 1973 through October 1977. 4-37
- 4-17. Abundance ($\#/m^3$) of *Temora longicornis* at Stations 3, 8 and 20; July 1973 through October 1977 4-41
- 4-18. Abundance ($\#/m^3$) of Copepoda nauplii and copepodites at Stations 3, 8 and 20; July 1973 through October 1977. 4-42
- 4-19. Abundance ($\#/m^3$) of Barnacle cyprids and nauplii at Stations 3, 8 and 20; July 1973 through October 1977. . . 4-44
- 4-20. Abundance ($\#/m^3$) of Polychaeta larvae at Stations 3, 8 and 20; July 1973 through October 1977. 4-46
- 4-21. Abundance ($\#/m^3$) of Gastropoda veligers and Bivalve larvae at Stations 3, 8 and 20; July 1973 through October 1977. 4-47
- 4-22. Abundance ($\#/m^3$) of Harpacticoida at Stations 3, 8 and 20; July 1973 through October 1977. 4-48
- 4-23. Overall percent composition of fish eggs of selected species in New Haven Harbor during each sampling period from 1974 through 1977. 4-57

4-24.	Overall percent composition of fish larvae of selected species in New Haven Harbor during each sampling period from 1974 through 1977.	4-58
4-25.	Abundance by station of <i>Anchoa</i> spp. eggs (during June 1975 through 1977; and July 1974 through 1977) and larvae (during July and August 1974 through 1977)	4-62
4-26.	Abundance by station of <i>Pseudopleuronectes americanus</i> larvae (during April and May 1975 through 1977) and <i>Cynoscion regalis</i> (during July 1974 through 1977)	4-64
4-27.	Abundance by station of Labrid eggs (during June), <i>Urophycis/Enchelyopus/Peprilus</i> eggs (during April and May).	4-70
4-28.	Mean density of selected species at all stations, depths and tides by month, July 1973-October 1977	4-77
4-29.	Mean density of selected species at all stations, depths and tides by month, July 1973 through October 1977.	4-78
4-30.	Mean density of selected species at all stations, depths and tides by month, July 1973 through October 1977.	4-79

LIST OF TABLES

	PAGE
4-1. DOMINANT ¹ PHYTOPLANKTERS IN NEW HAVEN HARBOR FROM 1974 THROUGH 1977.	4-16
4-2. MONTHLY RANKING OF THE TEN MOST ABUNDANT PHYTOPLANKTON TAXA (MEAN OF ALL STATIONS AND BOTH TIDES FROM MAY 1974 THROUGH OCTOBER 1977).	4-17
4-3. COMPARISON OF MAXIMUM CELL DENSITIES RECORDED FOR SEVEN DOMINANT SPECIES OF PHYTOPLANKTON DURING THE PRESENT STUDY WITH LITERATURE RECORDS FOR LONG ISLAND SOUND, AND GREAT SOUTH AND MORICHES BAYS	4-29
4-4. DOMINANT ¹ ZOOPLANKTERS IN NEW HAVEN HARBOR FROM 1973 THROUGH 1977.	4-36
4-5. MONTHLY RANKING [*] OF THE TEN MOST ABUNDANT ZOOPLANKTON TAXA (BASED ON MEAN OF ALL STATIONS AND BOTH TIDES FROM JULY 1973 THROUGH OCTOBER 1977).	4-39
4-6. NUMERICALLY DOMINANT (>1%) FISH EGGS AND LARVAE COLLECTED FROM NEW HAVEN HARBOR FROM 1974 THROUGH 1977.	4-50
4-7. DOMINANT SPECIES OF FISH EGGS REPORTED FROM LONG ISLAND SOUND AND ADJACENT WATERS FROM 1943 THROUGH 1975.	4-51
4-8. DOMINANT SPECIES OF FISH LARVAE REPORTED FROM LONG ISLAND SOUND AND ADJACENT WATERS FROM 1943 THROUGH 1975.	4-52
4-9. MEAN ABUNDANCE (NO./m ³) OF TOTAL FISH EGGS AND LARVAE COLLECTED FROM NEW HAVEN HARBOR FROM 1974 THROUGH 1977.	4-55
4-10. DOMINANT (>20%) FISH EGGS AND LARVAE, AND PERCENT COMPOSITION BY STATION IN NEW HAVEN HARBOR FROM 1974 THROUGH 1977.	4-56
4-11. COMPARISON OF ICHTHYOPLANKTON ABUNDANCE (NO./m ³) AT RICHARDS' (1959) STATION 1, 1952 THROUGH 1955 TO THE AVERAGE ¹ OF NEW HAVEN HARBOR STATIONS FROM 1974 THROUGH 1977.	4-60

4-12.	ABUNDANCE ($\#/m^3$) OF WINTER FLOUNDER (<i>PSEUDOPLEURO- NECTES AMERICANUS</i>) LARVAE IN NEW HAVEN HARBOR AND ADJACENT WATERS.	4-65
4-13.	ABUNDANCE ($\#/m^3$) OF WEAKFISH (<i>CYNOSCION REGALIS</i>) LARVAE IN NEW HAVEN HARBOR AND ADJACENT WATERS	4-67
4-14.	ABUNDANCE ($\#/m^3$) OF LABRID EGGS IN NEW HAVEN HARBOR AND ADJACENT WATERS	4-69
4-15.	ABUNDANCE ($\#/m^3$) OF <i>UROPHYCIS/ENCHELYOPUS/PEPRILUS</i> EGGS IN NEW HAVEN HARBOR AND ADJACENT WATERS	4-72
4-16.	RELATIVE DENSITIES OF SELECTED TAXA COMPARED BY MONTH BETWEEN OPERATIONAL AND PREOPERATIONAL YEARS. (OPERATIONAL DATA ADJUSTED FOR SAMPLING DIFFER- ENCES BY REGRESSION EQUATION)*	4-80

4.0 PLANKTON

by

Stephen Grabe, Doreen Newhouse, David Pease, and Neil Savage
Normandeau Associates, Inc.
Bedford, N. H.

INTRODUCTION

New Haven Harbor provides an extremely fertile habitat for phytoplankton due to its proximity to terrestrial nutrient sources and the protection against dispersal afforded by the configuration and shallowness of the harbor. Harbor waters also support substantial zooplankton and ichthyoplankton populations that ultimately depend on phytoplankton for food. Since most finfish and many benthic invertebrates, such as crabs and oysters, spend a portion of their lives in the plankton, any change in planktonic populations affects not only the food available to subsequent levels in the food web but also the magnitude of larval recruitment to adult populations of many aquatic animals.

Plankton investigations in southern New England waters in proximity to New Haven Harbor were begun by Yale University's Bingham Oceanographic Laboratory during the late 1930's. An early report by Riley (1941) focused on north central Long Island Sound. Between 1943 and 1949, investigative emphasis by the Bingham Laboratory shifted to Block Island Sound resulting in studies on phytoplankton (Riley, 1952), zooplankton (Deevey, 1952a; 1952b), and ichthyoplankton (Merriman and Sclar, 1952). A broad-scale survey of Long Island Sound conducted between 1952 and 1954 included studies on phytoplankton (S. Conover, 1956), zooplankton (R. Conover, 1956; Deevey, 1956) and ichthyoplankton (Wheatland, 1956). Results of subsequent studies of the Long Island Sound plankton community in 1954 and 1955 were reported by Riley and Conover (1967) for phytoplankton and by Richards (1959) for ichthyoplankton. Data from an additional ichthyoplankton survey conducted from April 1964 through May 1966 in the vicinity of Old Field Point near the southern shore of Long Island Sound, were reported by Williams (1968).

Primary sources of information pertaining to more recent plankton surveys include reports on studies performed for the Long Island Lighting Company (LILCO) at Shoreham Station (1973), Northport (1973, 1976), and Port Jefferson (1976). Data on phytoplankton, zooplankton, and ichthyoplankton are also contained in reports prepared for Northeast Utilities Service Company concerning environmental monitoring studies at Millstone Point (1971-1976) and Stamford (1971-1973). Williams (1971) discussed the influence of Northport Generating Station on the resident zooplankton community. Purdin (1973) presented a paper describing seasonal fluctuations in copepod populations in the vicinity of Shoreham Station. Caplan (1977) reported results of a six-month zooplankton and ichthyoplankton study on patterns of distribution in connection with a U.S. Army Corps of Engineers' dredge-spoil predisposal site study at Eaton's Neck in western Long Island Sound. Such data provide a useful perspective in evaluating observed fluctuations in New Haven Harbor plankton data.

In Long Island Sound, a major phytoplankton bloom typically occurs in late winter. A series of lesser blooms usually follow in spring, summer, and autumn. The timing and intensity of these blooms depend on a number of variables, among which are: 1) departures from the seasonal norm of sea temperature, 2) availability of inorganic nitrogen, and 3) zooplankton grazing pressure (TRIGOM-PARC, 1974). Diatoms, especially *Skeletonema costatum*, *Thalassiosira* spp., and *Thalassionema nitzschioides*, constitute the dominant net phytoplankters with dinoflagellates represented in substantial quantities, particularly during the warmer months. Species present represent a diverse mixture of temperate and boreal types, some with sheltered estuarine affinities and others with open coastal affinities (TRIGOM-PARC, 1974).

Among the invertebrate components of the Long Island Sound zooplankton, virtually every phylum in the animal kingdom is represented. Principal holoplankters (animals which spend their entire lives as plankton) are copepods, such as *Acartia tonsa*, *Acartia hudsonica* (= *clausi*), *Oithona* spp., *Paracalanus crassirostris*, *Temora longicornis*,

and *Pseudocalanus minutus*. The two *Acartia* species constitute the dominant zooplankters; *Acartia hudsonica* is characteristically the winter-spring dominant, while *A. tonsa* is typically the dominant in summer and fall. Among the microp plankton (embryonic and larval stages of animals which are not planktonic later in life), principal forms include the larvae of benthic invertebrates, such as barnacles, polychaete worms, molluscs, and echinoderms, as well as the larvae of epibenthic crustaceans (e.g., shrimps, crabs, and lobsters). The tycho plankton (transient epibenthic animals) was relatively sparse and was represented primarily by harpacticoid copepods.

Finfish eggs and larvae captured by net tows and reported for Long Island Sound and contiguous marine waters represent only a portion of the fish fauna inhabiting or frequenting the area. Early life stages of anadromous species are not present in Sound waters but are encountered in fresh or brackish waters. Some species that spawn in marine waters produce demersal eggs that sink and either lie loosely or are attached to various types of bottom substrate; generally, only newly hatched larvae of these species are found in the plankton. Fishes that shed planktonic eggs in marine waters tend to be those which range over wide areas of the open coast and/or continental shelf, and have a dispersed spawning pattern (TRIGOM-PARC, 1974). For Long Island Sound and vicinity, late winter through mid-summer is usually the period of high ichthyoplankton abundance, while for individual species, the planktonic period typically averages 3-5 months (Bigelow and Schroeder, 1953). Finfish species that are numerically dominant in the ichthyoplankton of Long Island Sound include eggs and larvae of *Tautogolabrus adspersus* (cunner), *Anchoa mitchilli* (bay anchovy), *Brevoortia tyrannus* (menhaden), and *Enchelyopus cimbrius* (four-beard rockling); eggs of *Tautoga onitis* (tautog); and larvae of *Ammodytes americanus* (sand lance) and *Pseudopleuronectes americanus* (winter flounder). In Long Island sound and adjacent waters successional periods of dominance in the ichthyoplankton appear to be as follows: *E. cimbrius*, mid-winter through late spring; *A. americanus* and *P. americanus*, early to late spring; *T. adspersus*, *T. onitis*, and *A. mitchilli*, late spring through mid-summer; and *B. tyrannus*, late spring and returning again in early fall (Wheatland, 1956; Richards, 1959; Caplan, 1977).

The following sections summarize phytoplankton, zooplankton and ichthyoplankton monitoring studies conducted as part of the New Haven Harbor Station Ecological Program for The United Illuminating Company from May 1971 through October 1977. Descriptions of methods are followed by discussions of the components of the New Haven Harbor plankton community and by an assessment of generating station operational impacts.

METHODS AND MATERIALS

Phytoplankton

Surface daytime whole-water samples were collected monthly for chlorophyll a determinations (May 1971 through October 1977) and phytoplankton taxonomic analysis (May 1972 through October 1977^{*}) during both flood and ebb tides at Stations 3, 6, 8, 18 and 20. Stations 2 and 11 were added to this sampling scheme in January 1974 and May 1975, respectively (Figure 4-1). Although primary productivity determinations utilizing the dissolved oxygen technique (Strickland, 1960; Strickland and Parsons, 1968) were conducted periodically from May 1971 through December 1974, these data are not considered herein due to anomalous results (including negative estimates of gross photosynthesis).

Each chlorophyll a sample was prefiltered through a 333 μ m mesh filter to remove debris and larger organisms, treated with approximately 2 ml of saturated $MgCO_3$ solution to retard degradation, and filtered through a glass fiber filter (.45 μ m pore size). Filters were kept frozen pending extraction. Chlorophyll a was extracted by macerating each filter in 90% aqueous acetone and centrifuging. Prior to July 1976, samples were analyzed by the spectrophotometric method (Strickland and Parsons, 1972). From July 1976 through October 1977, fluorescence was determined using a Turner fluorometer that had been calibrated

* From May 1971 through April 1972, phytoplankton were analyzed from 12.5 cm diameter, 76 μ m mesh Clarke-Bumpus net tows.

X - Phytoplankton
x = Chlorophyll a
o = Primary Productivity
F - Flood Tide
E - Ebb Tide

[illegible][illegible]

Figure 4-1. Phytoplankton, primary productivity and chlorophyll a samples collected from May 1971 to October 1977.
New Haven Harbor Ecological Studies Summary Report, 1979.

spectrophotometrically according to Strickland and Parsons (1972). After acidification with HCl, phaeophytin was determined and chlorophyll a concentrations (mg/m^3) were computed for each sample.

Following preservation with either formalin or Lugol's Iodine solution, aliquots were prepared from each phytoplankton sample and allowed to settle prior to enumeration, according to the Utermohl technique (1958). Prior to May 1974, phytoplankton taxa were generally identified only to major group; these data appear in earlier reports (NAI, 1973, 1974a, b). Beginning in May 1974, phytoplankton were identified to genus and species where possible, and abundance estimates (cells/l) were computed for each taxon.

An index of dominance (Sanders, 1960) was computed by ranking (from 10 to 1) mean abundances of individual phytoplankton taxa over all stations and tides during each month. Monthly ranks were summed for each taxon to yield yearly biological index values. Taxa were then ordered by biological index value as an indicator of overall dominance within each year.

The following phytoplankton species/taxa were selected for detailed discussion:

<i>Skeletonema costatum</i>	<i>Thalassiosira/Cyclotella</i> sp.
<i>Thalassionema nitzschioides</i>	<i>Leptocylindrus minimus</i>
<i>Heterocapsa triquetra</i>	Cryptophyceae

Zooplankton

Two-minute daytime plankton tows were collected monthly on both ebb and flood tides at near-surface and near-bottom water levels. From May 1971 through June 1976, collections were made at Stations 3, 6, 8, 18 and 20 utilizing a Clark-Bumpus (CB) sampler fitted with a 76 μm mesh net; Station 11 was added to this sampling scheme in May 1975

(Figure 4-1). From June 1975 through October 1977, a 0.5 m diameter conical net, fitted with a 158µm nylon mesh, was used. The new method was adopted because of a need to obtain more quantitative information on larger animals which appeared to possess some ability to avoid the smaller, slower-filtering sampler, and because the volume of the sample taken by the smaller net was concluded to be inadequate. For a period of 13 months (June 1975 through June 1976) the two collection methods described above were employed concurrently to evaluate comparability between them. In all cases sample volume was estimated using a mouth-mounted General Oceanics digital flowmeter.

In the laboratory, aliquots of zooplankton samples, which had been preserved in 5% gluteraldehyde, were extracted and placed in Sedge-wick-Rafter counting cells for identification and enumeration of the zooplankters present. Levels of taxonomic identification were determined by practical ability and interest in specific groups. Adults of numerically important copepods were differentiated to species, while most other groups (e.g., polychaetes, molluscs, and crustaceans other than copepods) were usually not differentiated beyond order or suborder. Abundance estimates (numbers/m³) were computed for each taxon.

Sanders' (1960) biological importance values were utilized to indicate overall dominance. Relative proportions of holoplankton, meroplankton, and tychoplankton were computed according to collection date, combining all stations, depths, and tides. Data collected prior to July 1973 are not presented herein and may be found elsewhere (NAI, 1973; 1974). The following 11 taxonomic/life-stage categories were selected for detailed presentation patterns because of their dominance in zooplankton collections from 1973 through 1977:

HOLOPLANKTON

Copepoda nauplii
 Copepoda copepodites
 Harpacticoida
Acartia tonsa
Acartia hudsonica
Temora longicornis

MEROPLANKTON

Polychaete larvae
 Gastropod veligers
 Bivalve veligers
 Barnacle nauplii
 Barnacle cyprids

To evaluate comparability of zooplankton collection methods, data collected during the 13-month period when both were in use were submitted to simple regression analysis. Population density estimates (numbers/m³) of nine abundant taxa from both methods were transformed to log₁₀ (x+1) values, matched by station, collection date, tide, and depth. Two versions of the regression analysis were employed: 1) data were matched where organisms of a particular taxon were captured by either one or both collection methods, and 2) data were matched only where both collection methods resulted in captures. The purpose of the second type of regression analysis was to indicate the position of the axis through the cluster of matched data points, disregarding those that fell directly on the x or y axis (i.e., which included a zero as one of the values in the pair). The rationale for this exclusion was that when the two methods yielded contradictory results on a presence-absence basis, clearly the method indicating absence was not sampling with any comparability to the other method, due either to differing thresholds of detection between methods or to real heterogeneity in the sampled environment. Simply stated, one method was completely ineffective at capture, regardless of the actual concentrations present. Inclusion of these points merely obscured the relationship between the two methods when both were effective.

Ichthyoplankton

Daytime ichthyoplankton collections were made monthly from May 1971 through May 1972 and from July 1974 through October 1977 (excluding January 1977) with a 1-m diameter plankton net outfitted with either 333µm (July 1974 through April 1975) or 505µm (May 1971 through May 1972

and May 1975 through October 1977) mesh netting and a mouth-mounted General Oceanics digital flowmeter that estimated the volume of water filtered by the net^{*}. Collections were made near both flood and ebb slack tides by 10-minute oblique net tows against the prevailing tide. Stations 3, 6, 8, 18 and 20 were sampled during all dates, and Station 11 was sampled from May 1975 through October 1977 (Figure 4-1). Samples were preserved in 5% formalin.

From June 1972 through June 1974, a 12.5-cm diameter Clarke-Bumpus sampler outfitted with 76 μ m mesh netting was used. Near-surface and near-bottom samples were collected by towing the net for two-minute intervals on both flood and ebb tides. Clarke-Bumpus collections were preserved in buffered 5% glutaraldehyde.

Data collected prior to July 1974 are not presented due to the methodological differences, which render the data noncomparable to latter years. Quality of the identifications is questionable, and quantitative accuracy is such that data should only be treated qualitatively. These data may be found in previous reports (NAI, 1973; 1974).

All fish eggs and larvae in a sample were counted and identified, except where organism densities were relatively large. In these cases, subsamples were taken so that the minimum number of eggs and larvae counted per aliquot were as follows:

<u>ALIQUOT SIZE</u>	<u>MINIMUM NUMBER TO BE IDENTIFIED</u>	
	<u>EGGS</u>	<u>LARVAE</u>
1/2	100	100
1/4	100	200
1/8	200	300
1/16	300	---
1/32	400	---

Density of fish eggs and larvae were expressed as number per m³.

* Collections from both 333 μ m and 505 μ m nets were assumed to be comparable.

Some species of eggs proved particularly difficult to identify to genus due to similar morphology and size (e.g., Labrid/*Limanda*^{*} and *Enchelyopus/Urophycis/Peprilus*) and were pooled. Based on numerical dominance as well as commercial and/or recreational importance, the following five taxa were selected for detailed discussion:

Anchoa spp. eggs and larvae
Pseudopleuronectes americanus larvae
Cynoscion regalis larvae
 Labrid eggs
Urophycis/Enchelyopus/Peprilus eggs

CHARACTERIZATION OF THE NEW HAVEN HARBOR PLANKTON COMMUNITY

Phytoplankton

In New Haven Harbor, phytoplankton biomass estimated by chlorophyll a concentrations generally remained at low levels (4 to 5 mg/m³) from September through January (Figure 4-2). From February through August, mean chlorophyll a concentrations were usually between 5 and 20 mg/m³; however, considerable inter-year variability was evident within each month, probably due to differences in timing and magnitude of phytoplankton blooms which may not be fully characterized by once-monthly sampling. From 1971 through 1975, chlorophyll a peaks only rarely exceeding 25 mg/m³ occurred between February and November (Figure 4-3). During 1976 and 1977, however, the frequency of occurrence of chlorophyll a peaks greater than 25 mg/m³ increased; in addition, unlike previous years, major late winter (February/March) peaks were also observed throughout the harbor.

Total phytoplankton cell density distributions from 1974 through 1977 indicated a general increase in standing stock over time (Figure 4-4). During 1974 and 1975, the seasonal phytoplankton abun-

* Eggs of the cunner and tautog (the only common Labridae in Long Island Sound) have been identified to species by Richards (Wheatland, 1956; Richards, 1959); however, characteristics adequate for positive identification of early stage eggs have not been documented.

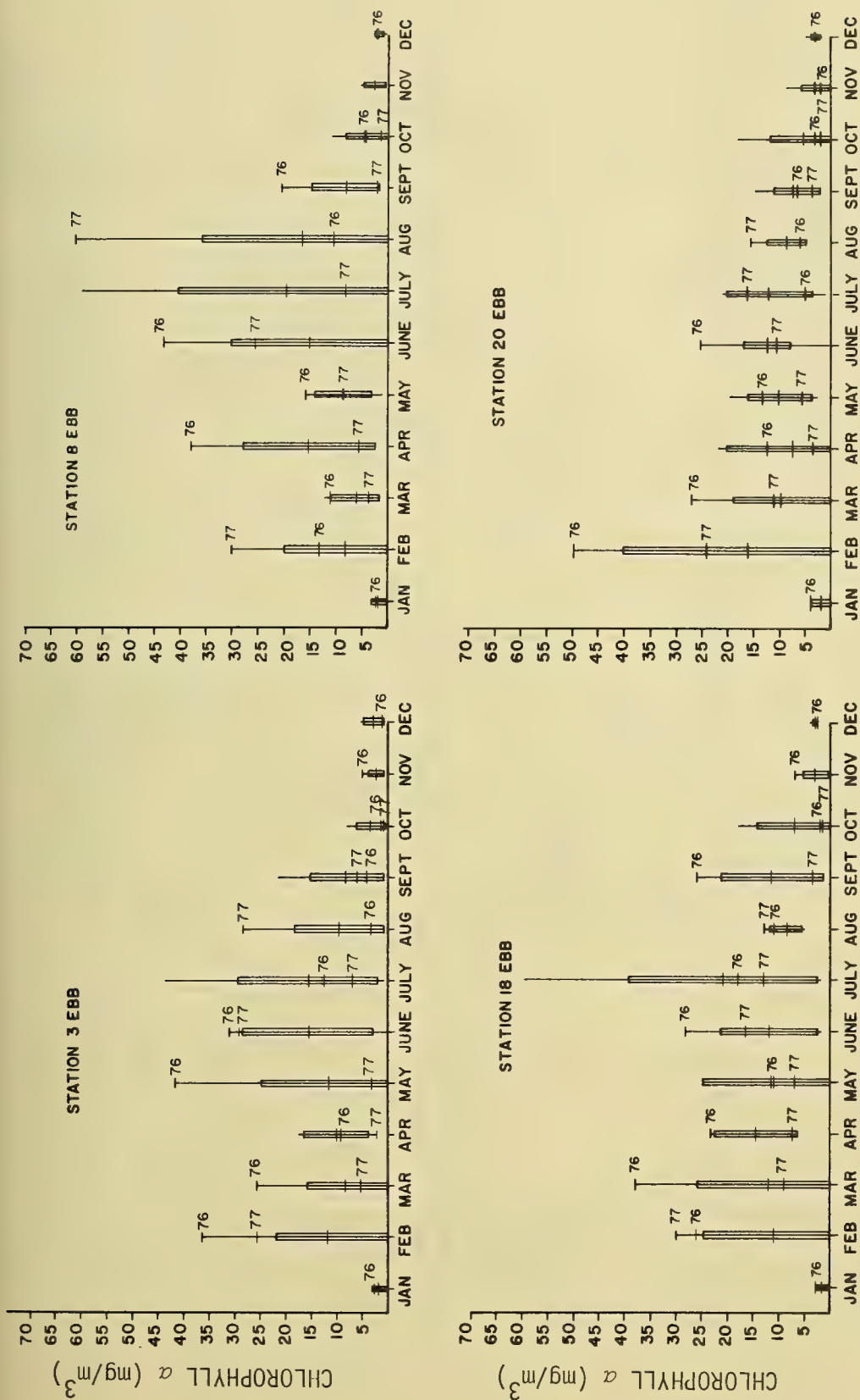


Figure 4-2. Monthly average chlorophyll *a* concentration (mg/m³), standard deviation and range for Stations 3, 8, 18 and 20 on ebb tide; May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

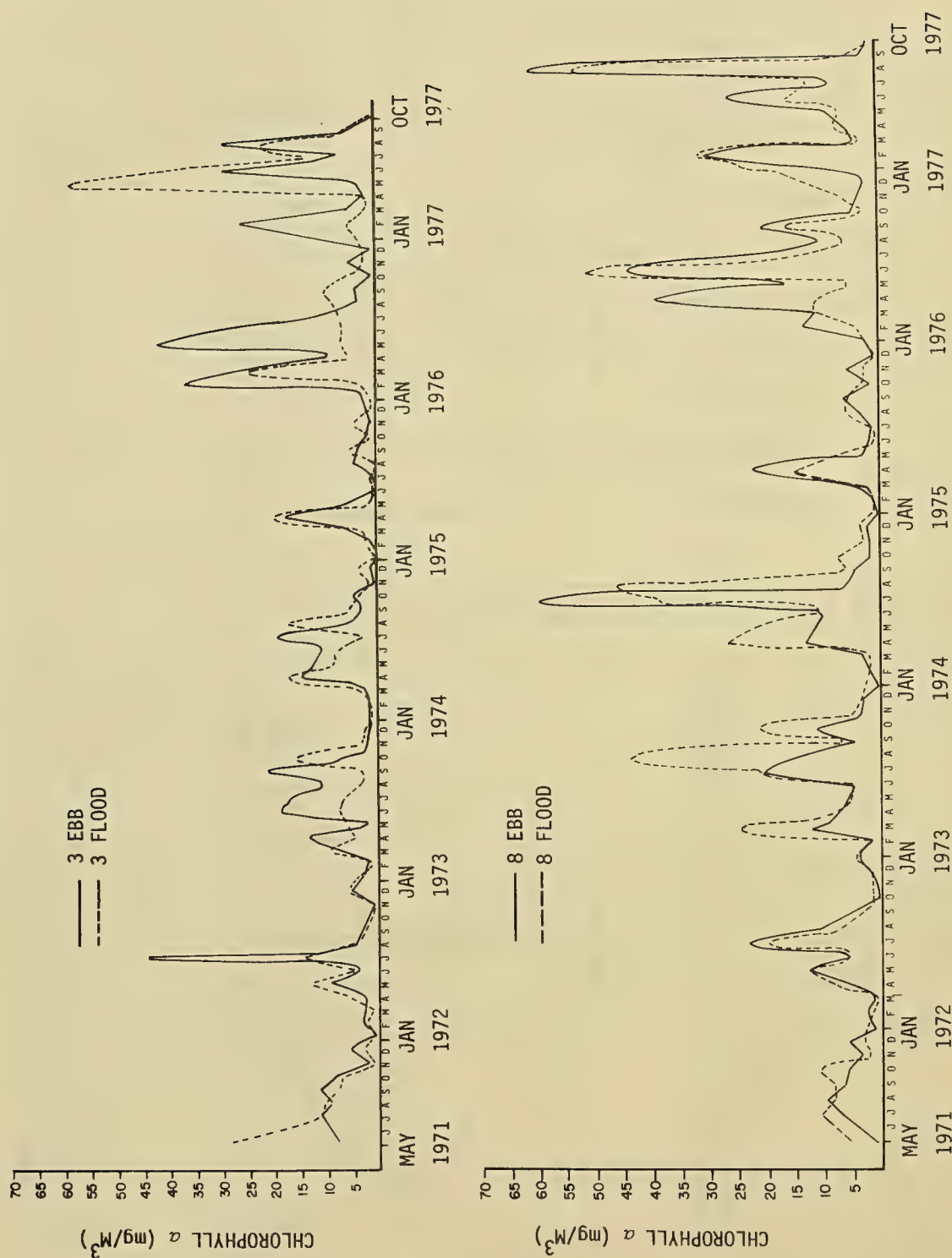


Figure 4-3. Monthly chlorophyll *a* concentrations (mg/m³) at Stations 3, 8, 18 and 20 on ebb and flood tide; May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

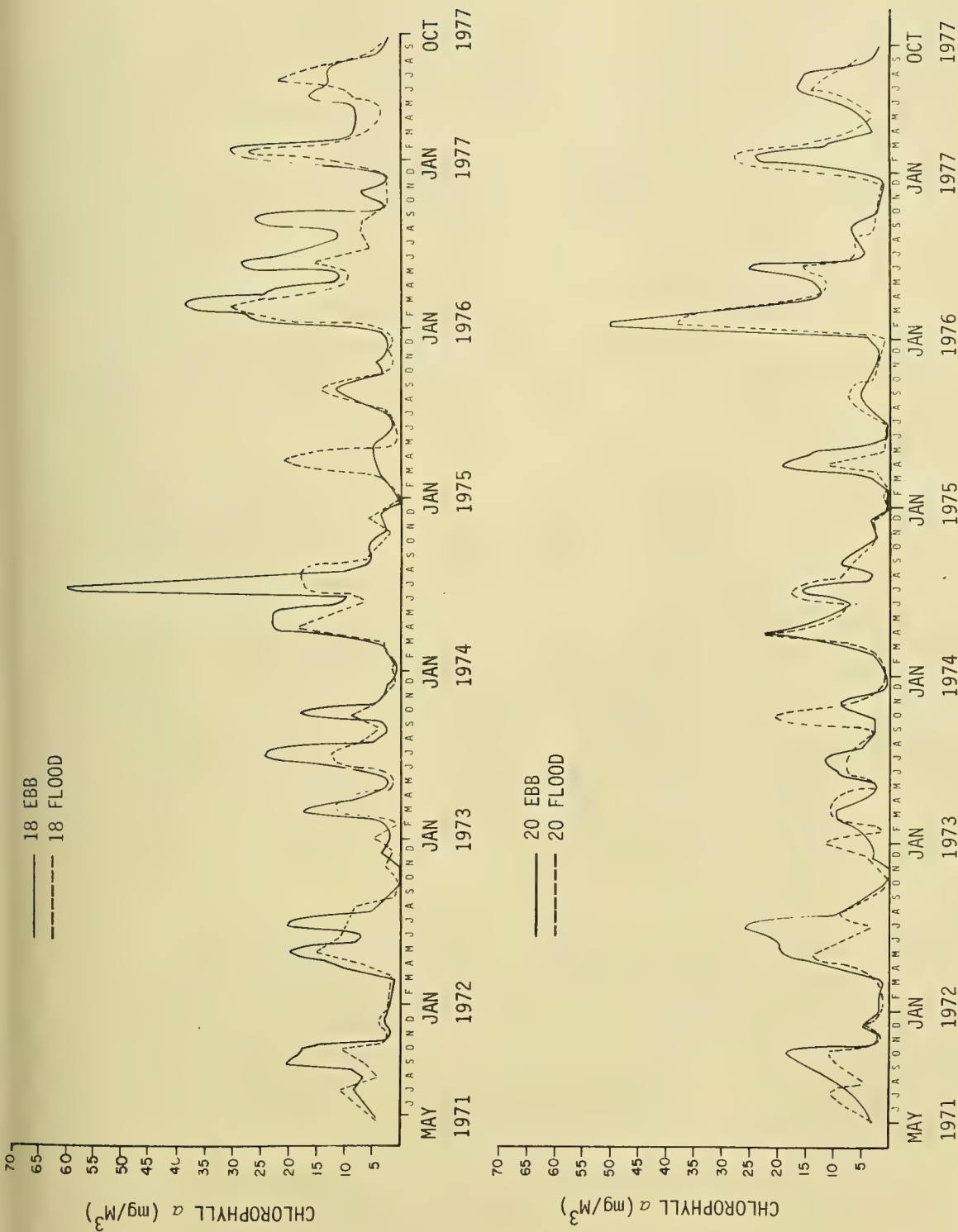


Figure 4-3. (Continued)

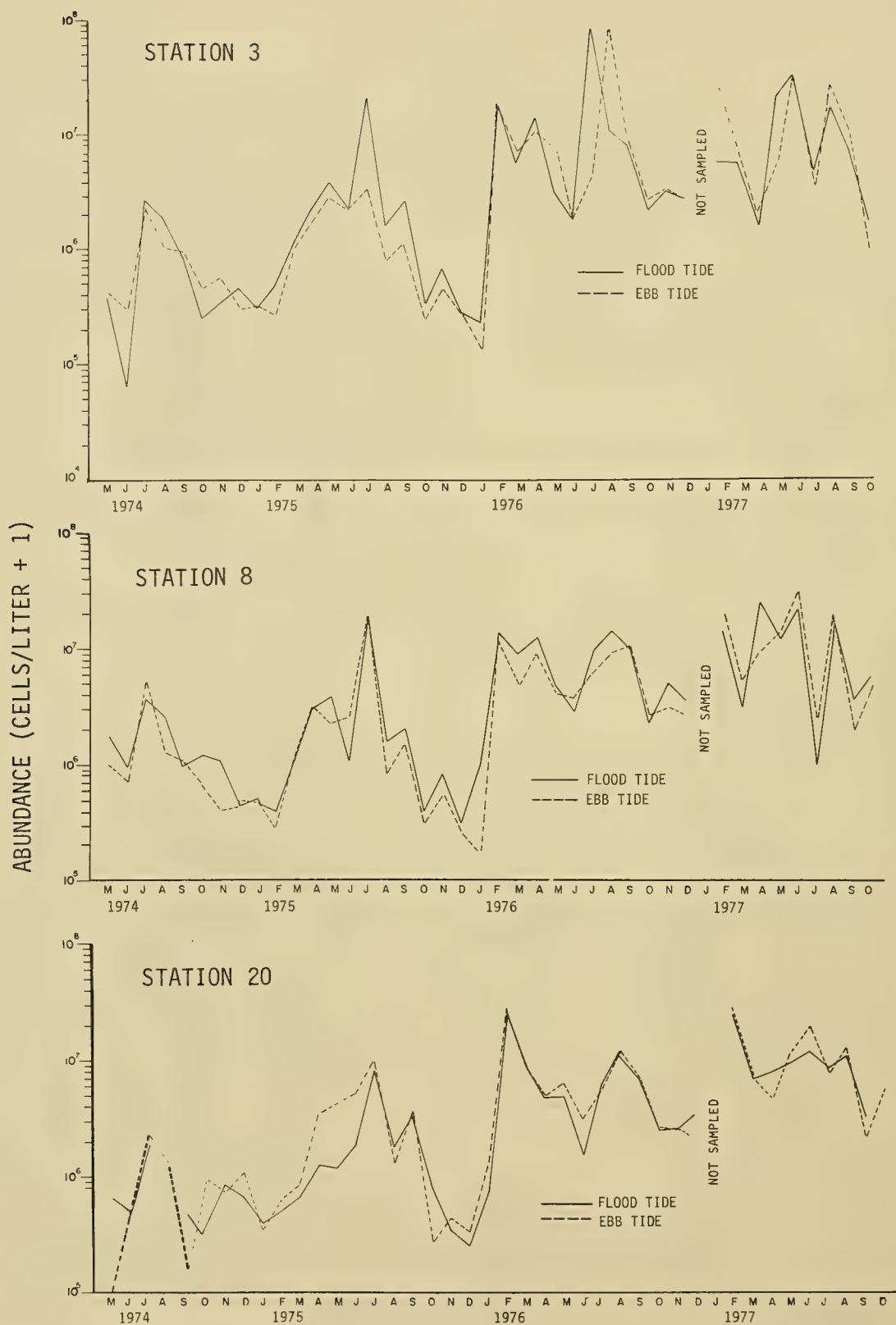


Figure 4-4. Total phytoplankton abundance (cells/liter) at Stations 3, 8 and 20 on ebb and flood tide; May 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

dance pattern was characterized by low densities (usually less than 10^6 cells/liter) from October through February and higher levels from March through September; peak densities (2×10^6 to 2×10^7 cells/liter) generally occurred during July and/or August. In 1976, the seasonal pattern changed to a rapid development from low January levels to a dramatic peak ($1-3 \times 10^7$ cells/liter) in February; in the outer harbor, a decline to a June minimum was followed by a second peak in August, while in the inner harbor the spring/summer peaks were more sporadic. In 1977, the February peak reoccurred (January was not sampled), and was followed by June and August peaks with additional station-dependent pulses during April and October (Figure 4-4).

From 1974 through 1977, the New Haven Harbor phytoplankton community was dominated by several species of centric diatoms (primarily *Skeletonema costatum* and a suite of *Thalassiosira/Cyclotella* species); microflagellates including cryptophytes (*Chroomonas* sp., *Rhodomonas* sp. and *Cryptomonas* sp.), chrysophytes (*Calycomonas* sp. and *Olisthodiscus luteus* and unspecified microflagellates); dinoflagellates (including *Heterocapsa triquetra* and *Katodinium rotundatum*); and pennate diatoms (primarily *Thalassionema nitzschioides*) (Table 4-1). *Skeletonema costatum*, *Thalassiosira/Cyclotella* species and microflagellates were among the ten dominant taxa during every month, while more seasonal contributions to community dominance were made by other taxa including dinoflagellates (generally late spring and summer) (Table 4-2).

The centric diatom, *Skeletonema costatum*, is eurythermal, euryhaline and cosmopolitan in distribution (Smayda, 1958) and has historically been an important component of the Long Island Sound phytoplankton community (Conover, 1956; Riley and Conover, 1967). In New Haven Harbor, *S. costatum* has been present ubiquitously and during all seasons since 1974 (Figure 4-5). In 1974 and 1975, blooms occurred from May through July and/or October. Abundance of this species has increased during the four-year period reported here; *S. costatum* has been present in bloom proportions (cell densities greater than 10^7 /liter) in July 1975, February 1976 and 1977, and June 1977 (Figure 4-5).

TABLE 4-1. DOMINANT¹ PHYTOPLANKTERS IN NEW HAVEN HARBOR FROM 1974 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	1974	1975	1976	1977	BIOLOGICAL INDEX
<i>Skeletonema costatum</i>	9	6	10	9	34
<i>Thalassiosira</i> sp.	6	8	8	8	30
Unspecified flagellates	1	10	9	10	30
<i>Cyclotella</i> sp.	10	9	3		22
<i>Thalassiosira pseudonana</i>	7	4		7	18
<i>Chroomonas</i> sp.	8	6			14
<i>Calycomonas</i> sp.	4	7	3		14
<i>Thalassionema nitzschioides</i>		2	7	4	13
<i>Chaetoceros</i> sp.			5	5	10
<i>Rhodomonas</i> sp.	5	5			10
Unspecified dinoflagellate			1	6	7
<i>Leptocylindrus minimus</i>			6		6
<i>Asterionella glacialis</i>			5		5
<i>Thalassiosira rotula</i>			4		4
<i>Thalassiosira nordenskioldii</i>				3	3
Unspecified Pennales		3			3
<i>Cryptomonas</i> sp.	3				3
<i>Euglena</i> sp.	2				2
<i>Phaeodactylum tricornutum</i>			2		2
<i>Katodinium rotundatum</i>				2	2
<i>Olisthodiscus luteus</i>				2	2
<i>Tetraselmis</i> sp.	1				1
<i>Asterionella formosa</i>		1			1
<i>Rhizosolenia fragilissima</i>				1	1

¹ Determined by ranking individually within each year followed by ranking biological index values for each year as a whole.

TABLE 4-2. MONTHLY RANKING OF THE TEN MOST ABUNDANT PHYTOPLANKTON TAXA (MEAN OF ALL STATIONS AND BOTH TIDES FROM MAY 1974 THROUGH OCTOBER 1977). NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

1974

	M	J	J	A	S	O	N	D	INDEX
<i>Cyclotella</i> sp.	9	5	8	10	5	4	9	6	56
<i>Skeletonema costatum</i>	10		9		8	10	10	8	55
<i>Chroomonas</i> sp.	7	7	6	7		8	6	3	44
<i>Thalassiosira pseudonana</i>	8	10	7	5	7	5			42
<i>Thalassiosira</i> sp.			5		3	7	8	10	33
<i>Rhodomonas</i> sp.	5	8		9			3	2	27
<i>Calycomonas gracilis</i>			2	4	10	2	5	23	
<i>Cryptomonas</i> sp.	2	6		1	6		7		22
<i>Euglena</i> sp.	4	4	4	6		1			19
Unspecified flagellates	6	3						4	13
<i>Tetraselmis</i> sp.			10	2			1		13
<i>Thalassionema nitzschioides</i>							5	7	12
<i>Chaetoceros curvisetus</i>					9	3			12
<i>Asterionella glacialis</i>	1					9			10
<i>Leptocylindrus minimus</i>			1				9		10
<i>Peridinium</i> sp.		9							9
<i>Phaeodactylum tricornutum</i>				8					8
<i>Scenedesmus</i> sp.	3	2			2				7
<i>Chaetoceros debilis</i>						6			6
<i>Chaetoceros</i> sp.			3			2			5
<i>Coelastrum</i> sp.					4				4
<i>Hemiselmsis</i> sp.							4		4
<i>Cryptophyceae</i>				3					3
<i>Pyramimonas</i>	1								1
<i>Rhizosolenia hebetata</i>					1				1
Unspecified Pennales								1	1

1975

	J	F	M	A	M	J	J	A	S	O	N	D	BI
Unspecified flagellates	10	10	9	3	2	5	6	6	7	10	6	8	82
<i>Cyclotella</i> sp.	9	8	7	8	6	3	9	7	2	8	5	7	79
<i>Thalassiosira</i> sp.	7	5	10	10	8					7	10	10	77
<i>Calycomonas</i> sp.	6	7	4	9	5		5	10	4	9	7	9	75
<i>Skeletonema costatum</i>	5	1	3	5	9	10	10		10	3			56
<i>Chroomonas</i> sp.	3	6	6		6	1	5	9	6	9	4		55
<i>Rhodomonas</i> sp.		3	5		1	7	8	9		4	4		41
<i>Thalassiosira pseudonana</i>					7	9	7	8					31
Unspecified Pennales	4	9	8	4					2		2		29
<i>Thalassionema nitzschioides</i>	8	4	2	7								6	27
<i>Asterionella formosa</i>					6					8	3		23
<i>Leptocylindrus minimus</i>									5	5	3	5	18
<i>Tetraselmis</i> sp.	2	2	1				4	1					10
<i>Cryptomonas</i> sp.						2	3	3			2		10
<i>Euglena</i> sp.						4	2		1	1	1		9
<i>Thalassiosira nordenskioldii</i>					8								8
<i>Chaetoceros curvisetus</i>									8				8
<i>Thalassiosira decipiens</i>								3					7
Unspecified Dinophyceae					3						1		4
Cryptomonadaceae									4				4
<i>Rhizosolenia delicatula</i>					2								2
<i>Pyramimonas</i> sp.								2					2
<i>Paralia sulcata</i>	1												1
<i>Nitzschia</i> sp.				1									1
<i>Fragilaria crotonensis</i>						1							1

1976

	J	F	M	A	M	J	J	A	S	O	N	D	BI
<i>Skeletonema costatum</i>	10	10	10	8	10	5	8	8	8	8	8	8	101
Unspecified flagellates	3		6	6	7	10	10	9	10	10	10		81
<i>Thalassiosira</i> sp.	6	1			9	9	9	10	9	9	9		71
<i>Thalassionema nitzschioides</i>	8	8	9	5	9	6					5	6	57
<i>Leptocylindrus minimus</i>	9	6	7	10	4				6	7			49
<i>Chaetoceros</i> sp.		1			3	3	6	7		6	7		33
<i>Asterionella glacialis</i>	2	7	5					7	2	3	3	4	33
<i>Thalassiosira rotula</i>	7	8	8										23
<i>Cyclotella</i> sp.					8	10							18
<i>Calycomonas</i> sp.		4	9	5									18
<i>Phaeodactylum tricornutum</i>								2	4	2	7		15
Unspecified dinoflagellate		2				7	3	3					15
Euglenophyceae						5	1	1	5				12
<i>Thalassiosira pseudonana</i>				4	7								11
<i>Prorocentrum redfieldi</i>						6		5					11
<i>Schroederella delicatula</i>		5	6										11
<i>Rhizosolenia delicatula</i>				7		2							9
Unspecified Pennales	1					1	4				3		9
<i>Thalassiosira nordenskioldii</i>										4	5		9
<i>Heterocapsa triquetrum</i>					8								8
<i>Cryptomonas</i> sp.									6	1			7
<i>Paralia sulcata</i>									4	2	1		7
<i>Detonula confervacea</i>	5										2		7
<i>Cylindrotheca closterium</i>						5							5
<i>Thalassiosira gravida</i>													4
<i>Chaetoceros curvisetus</i>	4												4
<i>Asterionella formosa</i>		4											4
<i>Euglena</i> sp.			3	1									4
<i>Tetraselmis</i> sp.				3									4
<i>Nitzschia delicatissima</i>						4							4
<i>Rhodomonas</i> sp.						3							3
<i>Prorocentrum minimum</i>							2		1				3
<i>Chaetoceros debilis</i>		2											2
<i>Peridinium</i> sp.					2								2
<i>Scenedesmus</i> sp.					1								1

1977

	J	F	M	A	M	J	J	A	S	O	N	D	BI
Unspecified flagellates	8	9	9	10	9	9	8	9	10				81
<i>Skeletonema costatum</i>	10	10	6	4	10	3	7	7	8				65
<i>Thalassiosira</i> sp.	7	6		9	6	2	8	6	6				51
<i>Thalassiosira pseudonana</i>				10	5		10	10	8	7			50
Unspecified dinoflagellate		1	4		5	7	5	5	5				32
<i>Chaetoceros</i> sp.		5	8					4	10				27
<i>Thalassionema nitzschioides</i>		6	4			8		3					21
<i>Thalassiosira nordenskioldii</i>		9	7										16
<i>Katodinium rotundatum</i>				8			6						14
<i>Olisthodiscus luteus</i>				7	7								14
<i>Rhizosolenia fragilissima</i>					6	7							13
Unspecified Pennales	2	3	1	2					4				12
<i>Cryptomonas</i> sp.					3					9			12
<i>Pyramimonas</i> sp.						1	5		4	2			12
<i>Phaeodactylum tricornutum</i>				5	5			1					11
<i>Rhizosolenia delicatula</i>					2	8							10
<i>Prorocentrum redfieldi</i>							8						8
<i>Asterionella glacialis</i>	3									3			6
<i>Leptocylindrus minimus</i>						3				2	1		6
<i>Cylindrotheca closterium</i>								6					6
<i>Ankistrodesmus</i> sp.					1	4							5
<i>Paralia sulcata</i>		2							2				
<i>Detonula confervacea</i>	4												4
<i>Oxytoxum</i> sp.							4						4
<i>Asterionella formosa</i>							3						3
Euglenophyceae									3				3
<i>Olisthodiscus</i> sp.									3				3
<i>Gymnodinium</i> sp.					2								2
<i>Lithodesmium undulatum</i>									2				2
<i>Chaetoceros affinis</i>										1			1
<i>Leptocylindrus danicus</i>	1												1
<i>Closterium</i> sp.								1					1

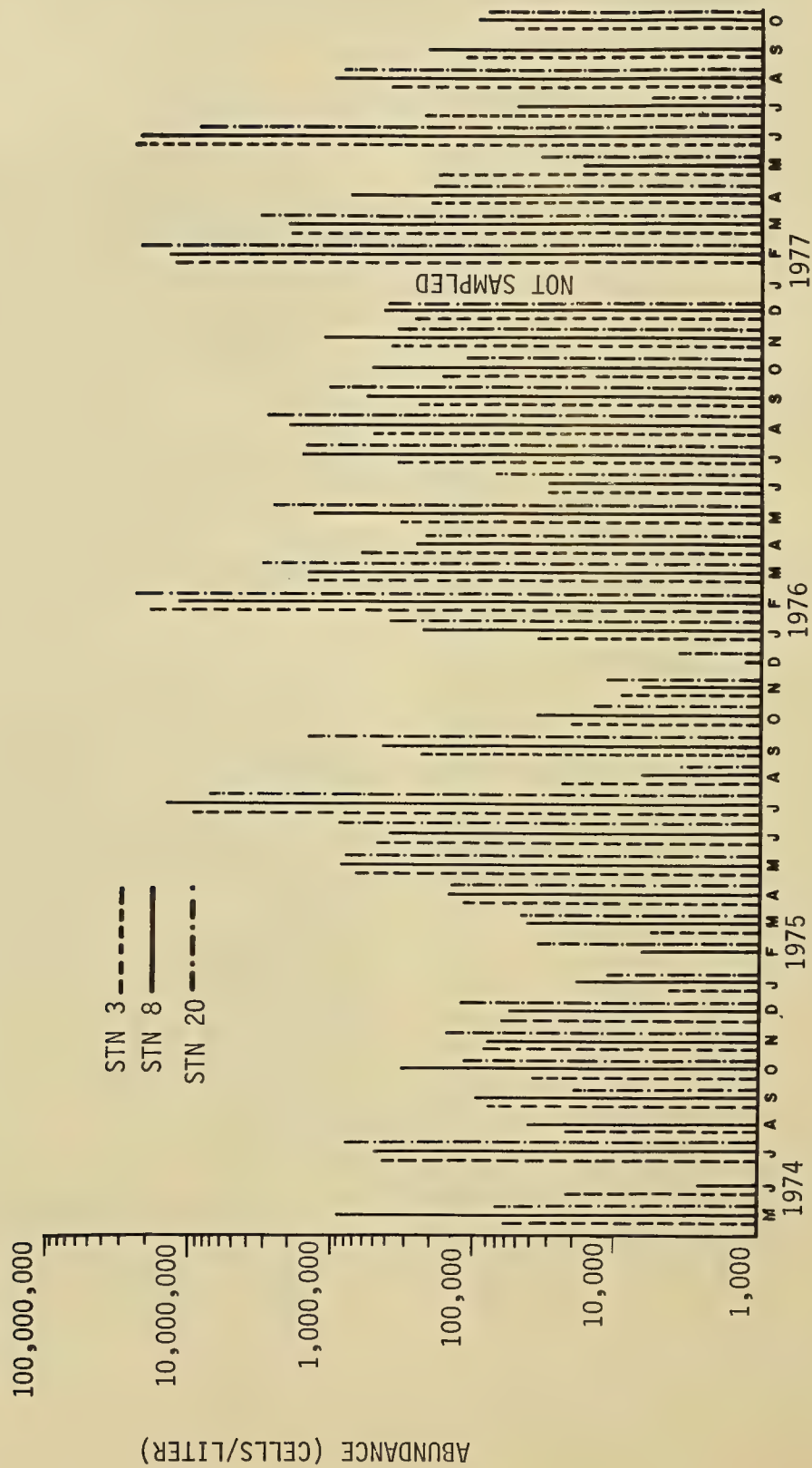


Figure 4-5. Abundance (cells/liter) of *Skeletonema costatum* at Stations 3, 8 and 20; May 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Thalassiosira/Cyclotella species represent a suite of species including *T. pseudonana* (= *Cyclotella nana*), *T. rotula* and *T. nordenskioldii*. *T. nordenskioldii*, an important component of the Long Island Sound phytoplankton community, was considered by Conover (1956) to exhibit best growth during late-winter conditions of low light and temperature. In New Haven Harbor, *T. nordenskioldii* was dominant in May 1975, and may have also been the major component of the *Thalassiosira* sp. bloom from January through June and October through December of that year (Table 4-2; Figure 4-6). *T. nordenskioldii* was again dominant from November 1976 through March 1977. Thus, along with *S. costatum*, *T. nordenskioldii* probably contributed to the major late-winter phytoplankton blooms 1975 through 1977.

Within the *Thalassiosira/Cyclotella* suite, *Thalassiosira pseudonana* was the dominant taxon differentiated to species (Table 4-1). It reportedly experiences good growth at salinities from 4 ‰ to 30 ‰ (Guillard and Ryther, 1962), and large blooms ($>5 \times 10^8$ cells/l) have been recorded in Great South and Moriches Bay, Long Island (Hulburt, 1970). In New Haven Harbor, abundance peaks (10^5 - 10^6 cells/l) occurred in May, June and/or July from 1974 through 1976 (Figure 4-7). In 1977, however, peaks in April and August approached 10^7 cells per liter and appeared to be highest in the inner harbor. *T. pseudonana* probably contributed to the *Cyclotella* spp. and *Thalassiosira* spp. peaks observed from 1974 through 1977 (Figure 4-6, 4-7).

Thalassionema nitzschioides is a cosmopolitan, principally-neritic pennate diatom (Smayda, 1958) which experiences best growth at low light and temperature levels but possesses wider tolerances in southern stocks (Riley and Conover, 1967). In New Haven Harbor, *T. nitzschioides* has been consistently dominant from December through February; during 1976 it was a dominant during all months except July through October and in 1977 it was dominant in February, March, June and August (Table 4-2). Highest densities (greater than 10^6 cells/liter) occurred during March and May 1976 and in June 1977 (Figure 4-8).



Figure 4-6. Abundance (cells/liter) of *Cyclotella* spp., *Thalassiosira rotula* and *Thalassiosira* spp. at Stations 3, 8 and 20; May 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

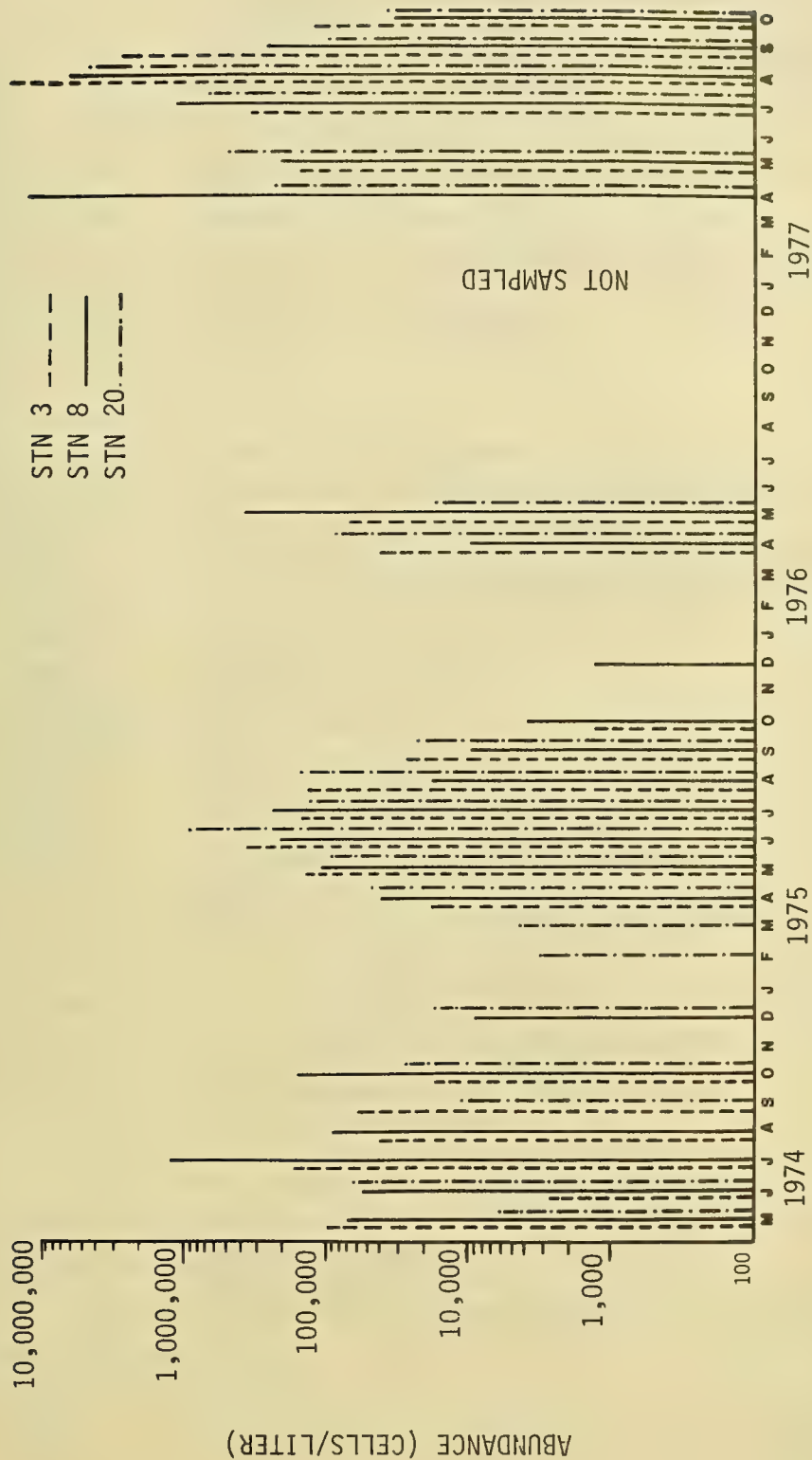


Figure 4-7. Abundance (cells/liter) of *Thalassiosira pseudonana* at Stations 3, 8 and 20; May 1974 through October 1979. New Haven Harbor Ecological Ecological Studies Summary Report, 1979.

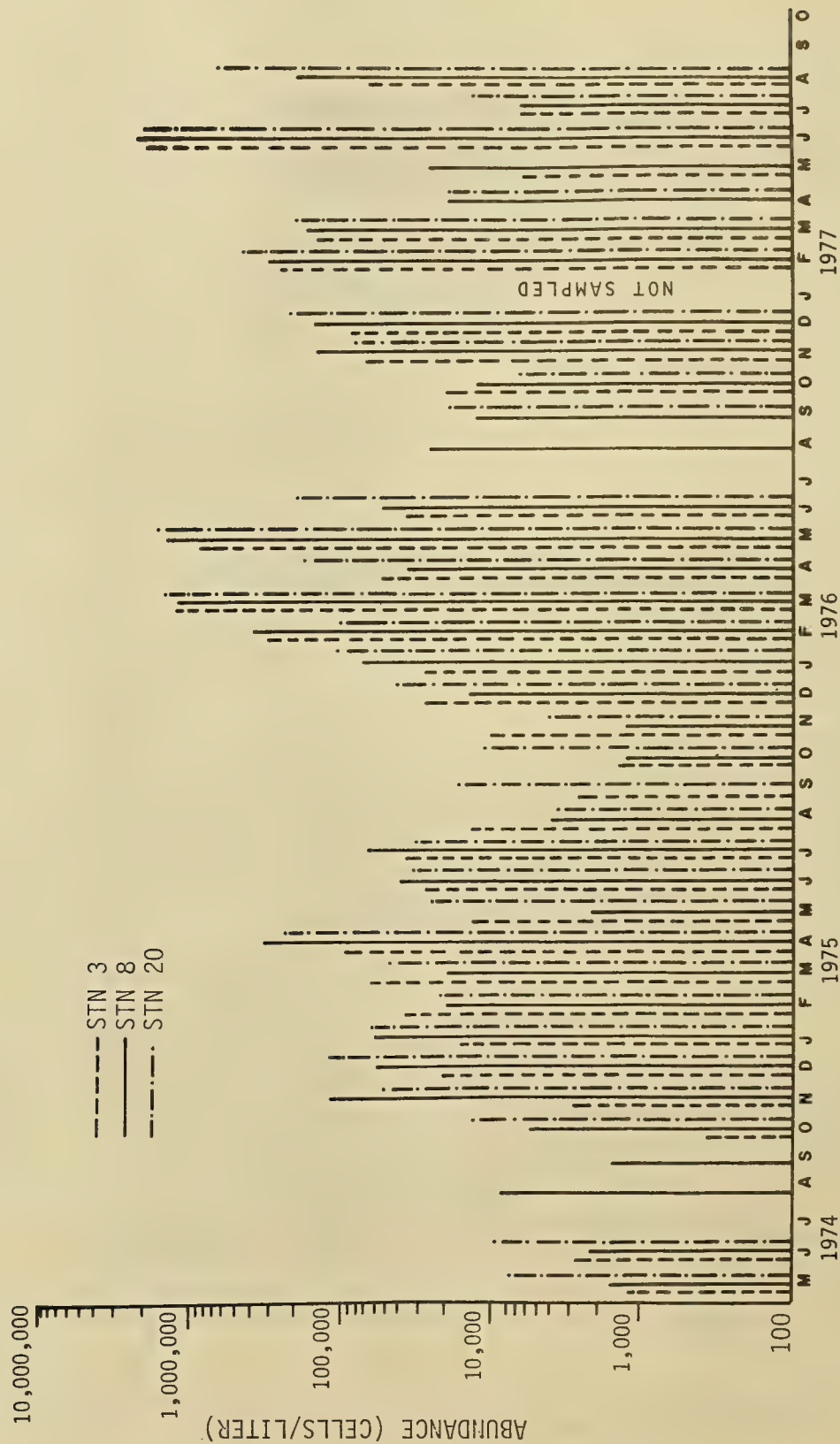


Figure 4-8. Abundance (cells/liter) of *Thalassionema nitsochoides* at Stations 3, 8 and 20; May 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Leptocylinndrus minimus is a boreal, neritic diatom reportedly associated with the spring *Thalassiosira* bloom in the Gulf of Maine (Lillick, 1940). *L. minimus* is difficult to distinguish from *L. dani-cus*, which was considered a major dominant in Long Island Sound (Conover, 1956; Riley and Conover, 1967). In New Haven Harbor, a major bloom (10^6 to 10^7 cells/liter) of *L. minimus* occurred during April 1976 (Figure 4-9) following a period of consistent dominance that began in September 1975 (Table 4-2). This species was also dominant during July and December 1974, September/October 1976 and less so during May, September and October 1977.

Dinoflagellates have generally occurred as dominants during late spring and summer in New Haven Harbor (Table 4-2) as has historically been the case for Long Island Sound (Conover, 1956; Riley and Conover, 1967). In June 1974, a non-toxic red-water bloom of the dinoflagellate *Peridinium* sp. (which may have been *Heterocapsa triquetra* = *Peridinium triquetrum*) was observed. In 1975, dinoflagellates were dominant sporadically only during May and December. During 1976, several dinoflagellates were dominant from April through October; major features were the reoccurrence of a *Heterocapsa triquetra* bloom in June and blooms of unspecified taxa and *Prorocentrum* spp. primarily from July through September (Table 4-2). In 1977, unspecified dinoflagellates were among the ten dominant taxa from March through October, with additional blooms of *Heterocapsa triquetra* in February (Figure 4-10), *Katodinium rotundatum* in April (Table 4-2) and July and *Prorocentrum redfieldii* in July (Table 4-2).

Microflagellates have been consistent dominants in New Haven Harbor, although prior to July 1976 unspecified taxa were probably underestimated during microscopic examination (NAI, 1977). During 1977, for example, unspecified microflagellates were consistently dominant, with abundances ranging from 3×10^5 to 9×10^6 cells/l (NAI, 1978). Of the microflagellate taxa identified to genus, two cryptophycean genera (*Chroomonas* sp. and *Rhodomonas* sp.) appeared as overall dominants in 1974 through 1975, and a third cryptophycean (*Cryptomonas* sp.) was an overall dominant in 1974 only (Table 4-1). In 1976 and 1977, *Chroomonas*



Figure 4-9. Abundance (cells/liter) of *Leptocylindrus minimus* at Stations 3, 8 and 20; May 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

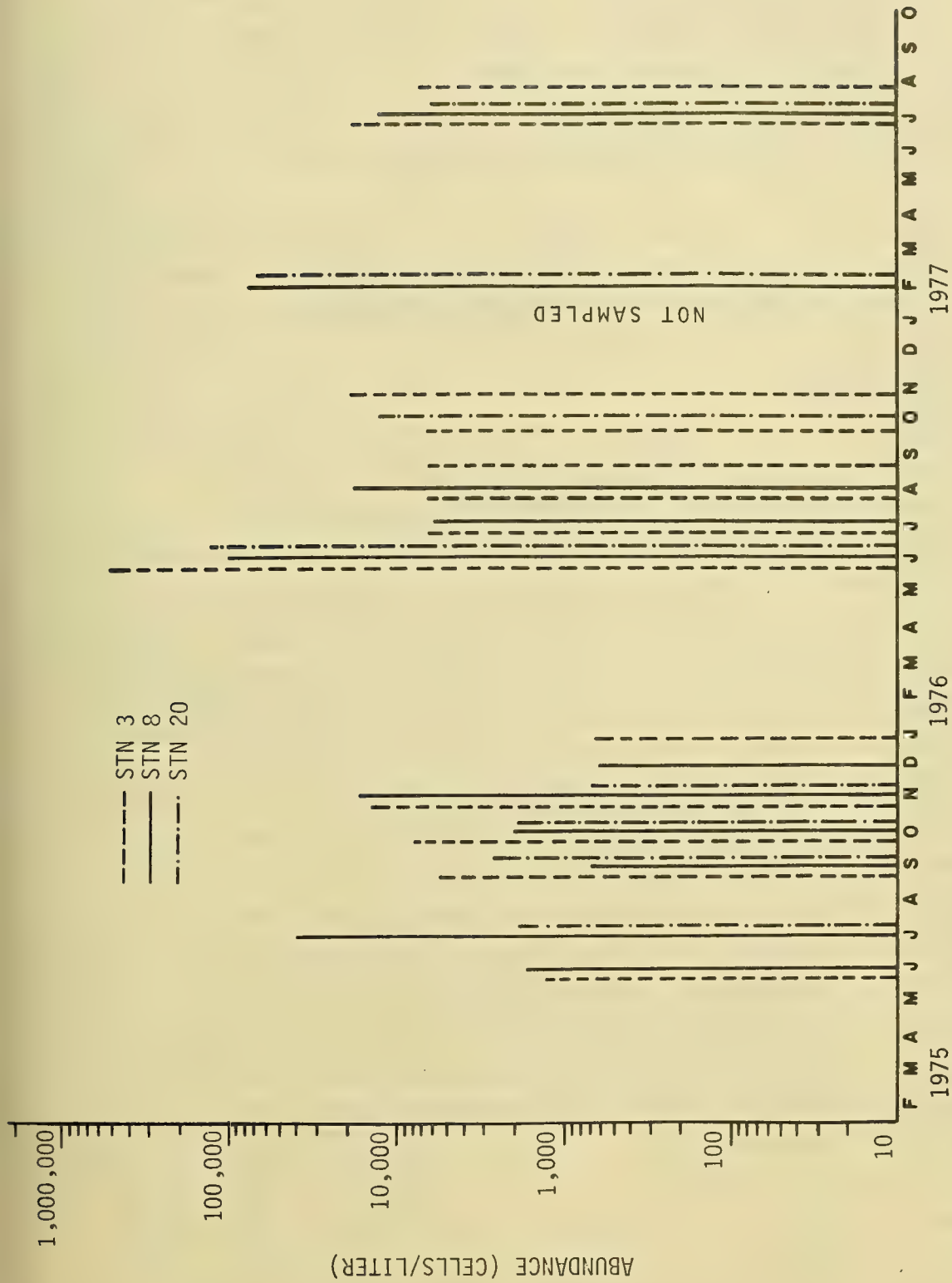


Figure 4-10. Abundance (cells/liter) of *Heterocapsa triquetra* at Stations 3, 8 and 20; January through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

sp. was not a dominant taxon; *Rhodomonas* sp. was a dominant in May (1976) and *Cryptomonas* sp. was a dominant in April (1977), October (1976 and 1977) and November (1976) (Table 4-2). Abundance of Cryptophyceae from 1974 through 1977 is presented in Figure 4-11; their apparent reduced occurrence and dominance during the latter half of 1976 and in 1977 may have been an artifact resulting from the inclusion of members of this group with the unspecified flagellate group during this period.

In summary, phytoplankton cell densities and chlorophyll a concentrations in New Haven Harbor from 1974 through 1977 were generally lowest from October through January. During this period the diatoms, *Skeletonema costatum* and *Thalassiosira/Cyclotella* spp., and microflagellates usually dominated the phytoplankton assemblage. Other diatoms, most notably *Thalassionema nitzschioides*, *Leptocylindrus minimus*, and *Asterionella* spp. also appeared during this period. From February through April, during which time cell densities and chlorophyll a concentrations generally peaked, several diatoms and microflagellates achieved prominence. In 1975 during this late-winter/early spring period, *Thalassiosira/Cyclotella* spp., unspecified pennate diatoms and flagellates, *Thalassionema nitzschioides*, *Asterionella formosa*, *Calycomonas* sp., *Chroomonas* sp., and *Rhodomonas* sp. were dominants. In 1976 a major bloom of *Skeletonema costatum* was responsible for the cell density maximum in February and was succeeded by blooms of *T. nitzschioides*, *T. rotula*, *Schroderella delicatula* and *Asterionella glacialis* in March, and *Leptocylindrus minimus* and *Calycomonas* sp. in April. In 1977, a major February bloom of *Skeletonema costatum* reoccurred, and persisted into March when it was accompanied by unspecified flagellates, *Chaetoceros* sp., *Thalassiosira nordenskioldii* and *Thalassiosira* sp., and *Phaeodactylum tricornutum*; in April, of *T. pseudonana*, unspecified flagellates, *Olisthodiscus luteus*, and the dinoflagellate, *Katodinium rotundatum*, were dominant. In May from 1974 through 1976 *Skeletonema costatum* and *Thalassiosira/Cyclotella* spp. were dominant; in 1976, however, *T. nitzschioides* was also important. In May 1977, unspecified flagellates and *Olisthodiscus luteus* as well as the diatoms, *Thalassiosira* sp. and *Rhizosolenia* spp., were dominant. During June and July, *Thalassiosira/Cyclotella* species (including *T. pseudonana*), dinoflag-

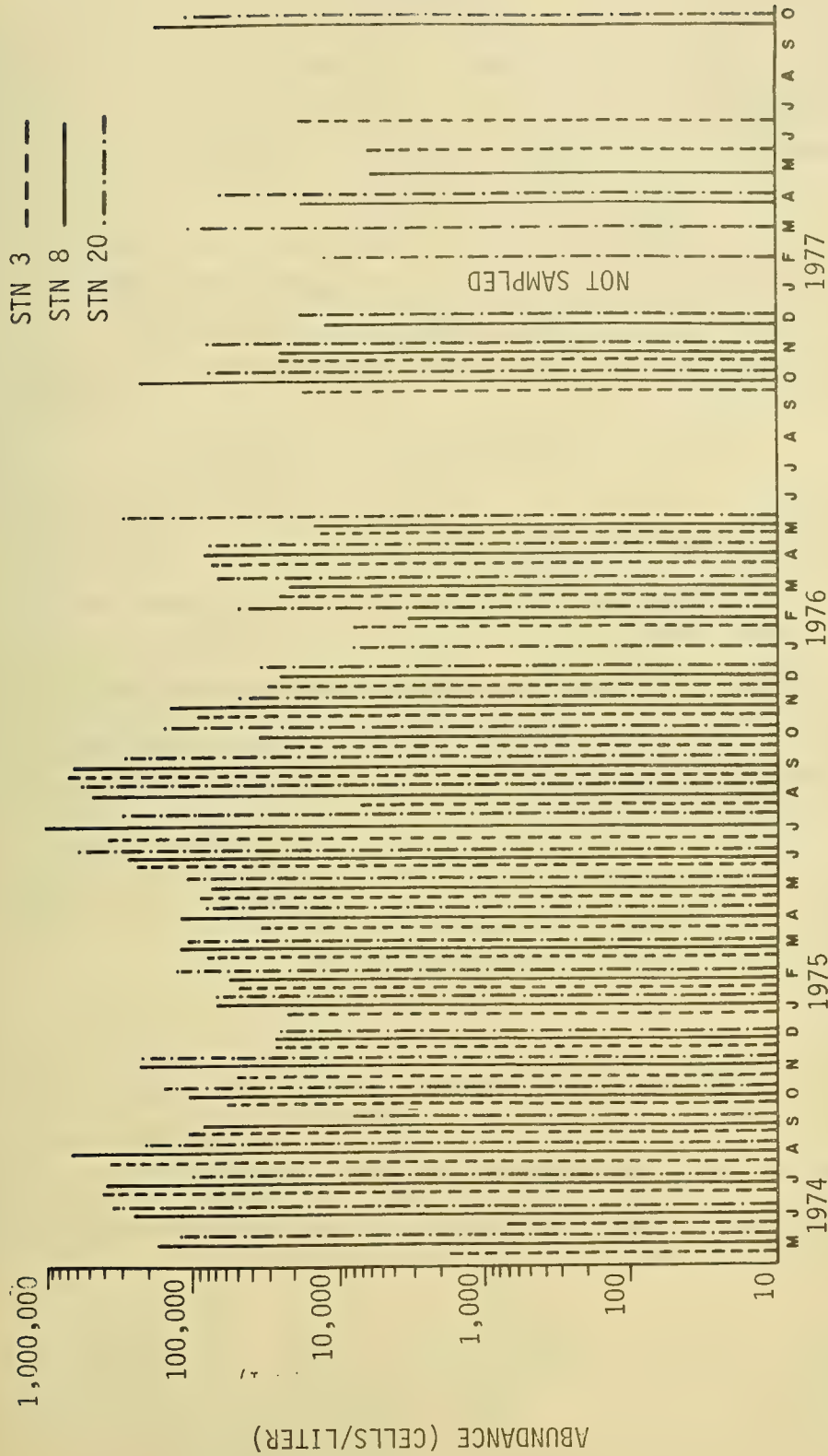


Figure 4-11. Abundance (cells/liter) of Cryptophyceae at Stations 3, 8 and 20; May 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

ellates (including *H. triquetra*), unspecified flagellates and *Skeletonema costatum* (June 1975 through 1977; July 1974 through 1977) were dominant. August's community was usually dominated by flagellates and *Thalassiosira/Cyclotella* species (including *T. pseudonana*); *Skeletonema costatum* (1976 and 1977), *Chaetoceros* sp. (1976 and 1977), and pennate diatoms (*P. tricornutum* in 1974, unspecified Pennales in 1975 and 1976, *C. closterium* in 1976 and 1977, and *A. glacialis* in 1976) were also dominant in August. During September, flagellates continued to dominate with diatoms such as *Skeletonema costatum* (1974 through 1977), *Chaetoceros* spp., *C. curvisetus* in 1974 and 1975 and *Chaetoceros* sp. in 1976 and 1977, *Thalassiosira/Cyclotella* sp. (1974 through 1977), and *Leptocylindrus minimus* (1975 through 1977).

A comparison of maximum cell densities recorded for seven of the dominant species during the present study compared with literature records for Long Island Sound and Great South and Moriches Bays, is presented in Table 4-3. Similar order-of-magnitude densities were found for all but *Thalassionema nitzschoides* whose peak New Haven Harbor densities were higher than those reported for Long Island Sound, and *Thalassiosira pseudonana* which was less dense in New Haven Harbor than in Great South and Meriches Bay.

Characterization of the New Haven Harbor Zooplankton

Characterization of the New Haven Harbor zooplankton in this study relies on data produced by two different methods of sampling and laboratory analysis. Further, because the second method was instituted just several months prior to the plant going on line, understanding of the differences in density estimates based on the two different methods is vital to analysis of impacts.

Results of a 13-month comparability study are presented in detail in Appendix 4-1. The foremost observation is that the two methods yielded radically different density estimates. Of the two methods, the

TABLE 4-3. COMPARISON OF MAXIMUM CELL DENSITIES RECORDED FOR SEVEN DOMINANT SPECIES OF PHYTOPLANKTON DURING THE PRESENT STUDY WITH LITERATURE RECORDS FOR LONG ISLAND SOUND, AND GREAT SOUTH AND MORICHES BAYS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

MAXIMUM CELL DENSITIES
(CELLS/LITER)

	LITERATURE REPORTS	PRESENT STUDY
<i>Skeletonema costatum</i>	$>3.0 \times 10^7$ (1) 1.1×10^7 (2)	$1-3 \times 10^7$
<i>Thalassiosira pseudonana</i>	5.5×10^8 (3)	1×10^7
<i>Thalassionema nitzschioides</i>	6.0×10^5 (1) 8.7×10^5 (2)	$1-2 \times 10^7$
<i>Leptocylindrus minimus</i>	9.1×10^6 (1) 1.2×10^5 (2)	$1-10 \times 10^6$
<i>Thalassiosira rotula</i>	3.8×10^5 (1) 7.7×10^5 (2)	1×10^6
<i>Heterocapsa triquetra</i>	4.0×10^5 (2)	$1-4 \times 10^5$
<i>Thalassiosira nordenskioldii</i>	6.0×10^6 (1) 2.9×10^5 (2)	9.7×10^5

(1) Long Island Sound; Conover (1956)

(2) Long Island Sound; Riley and Conover (1967)

(3) Great South and Moriches Bay; Hulburt (1970)

earlier, Clarke-Bumpus (CB) method was considerably less accurate. CB determinations were characterized by a high threshold density for taxa detection (100 to 200 per m³). Below threshold, taxa densities were underestimated: when organisms were most abundant, densities were overestimated. In addition, though the reverse also occurred, there were far more instances when the CB yielded no organisms of a particular taxon while the half-meter net (1/2 meter) indicated organism presence. Lower sample volumes, higher clogging rates and, perhaps, higher avoidance rates combined to make the CB method inconsistent in estimation of organisms present at low densities, and less accurate overall.

Comparisons of data derived from the two methods must be made with care, and any comparisons of study results to be made which require cross-method comparisons should be based on sets of data and not on individual samples or stations. In broad terms, regression equations show that CB estimates ranged up to 1.5 orders of magnitude higher than 1/2-meter estimates at the lower end of the density range observed in the harbor. At highest observed densities, 1/2-meter estimates were in the same range as those derived from CB samples. For copepod nauplii and polychaete larvae, CB estimates were nearly always higher than 1/2-meter estimates over the observed density range. For certain taxa, over the observed range of values, CB estimates were generally higher than 1/2-meter at lower observed densities: at highest observed densities estimates were about even with the two methods. These taxa included copepod copepodites, cirripedia nauplii, and gastropod veligers. *Acartia* spp. seem to have been equally estimated by the two methods at lower observed densities but at the upper range of observed densities 1/2-meter sampling yielded higher densities than CB sampling.

From 1973 through 1976, total zooplankton abundances in New Haven Harbor were usually at lowest seasonal levels in December and January (Figures 4-12 and 4-13). Abundances generally increased to seasonal peaks by March or April (1974 through 1976); in 1977, this peak was delayed until May/June. This delay may have been related to the exceptionally cold winter of 1976-1977, although no definite connection

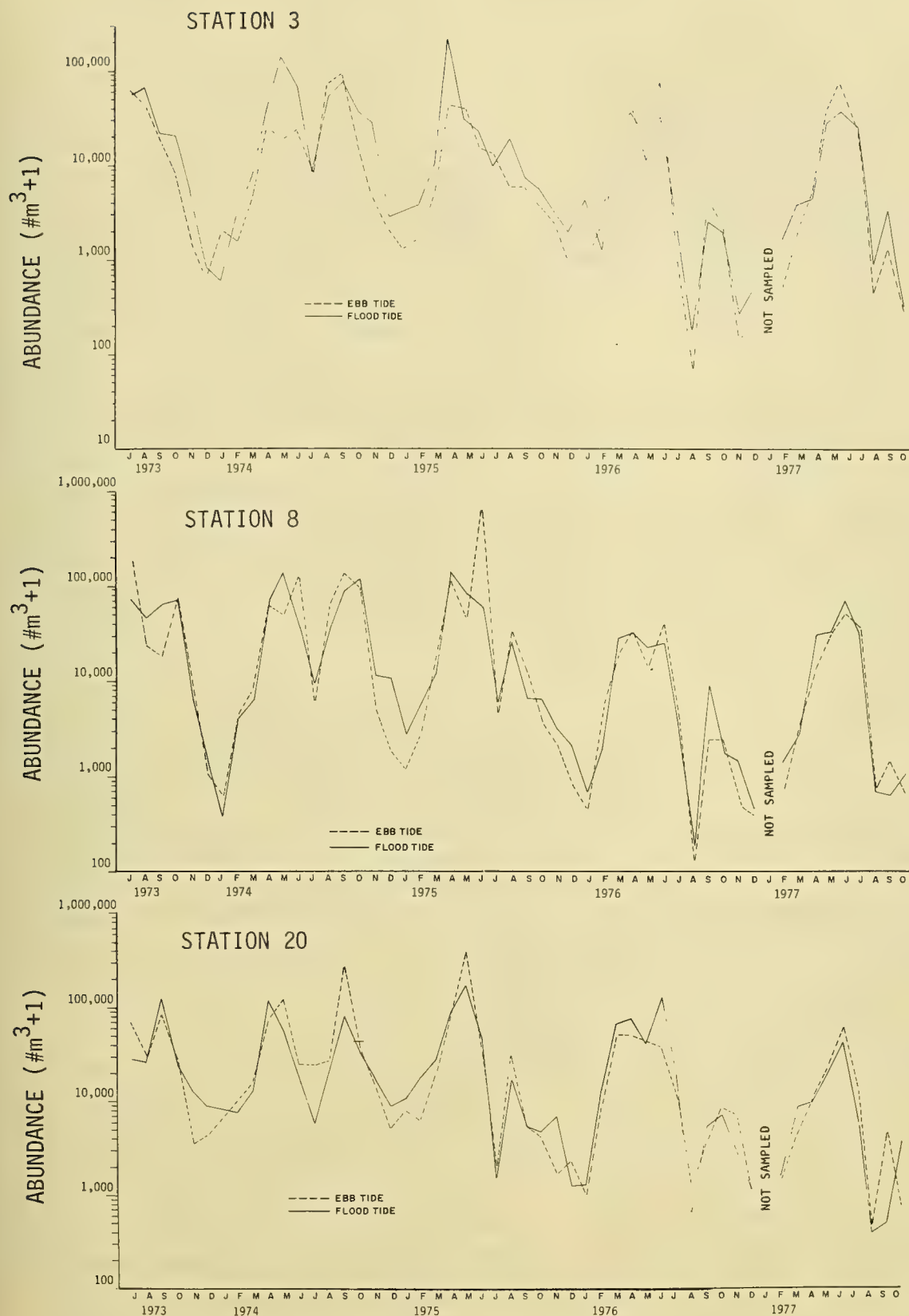


Figure 4-12. Total zooplankton ($\#m^3$) at Stations 3, 8 and 20 on ebb and flood tide; July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

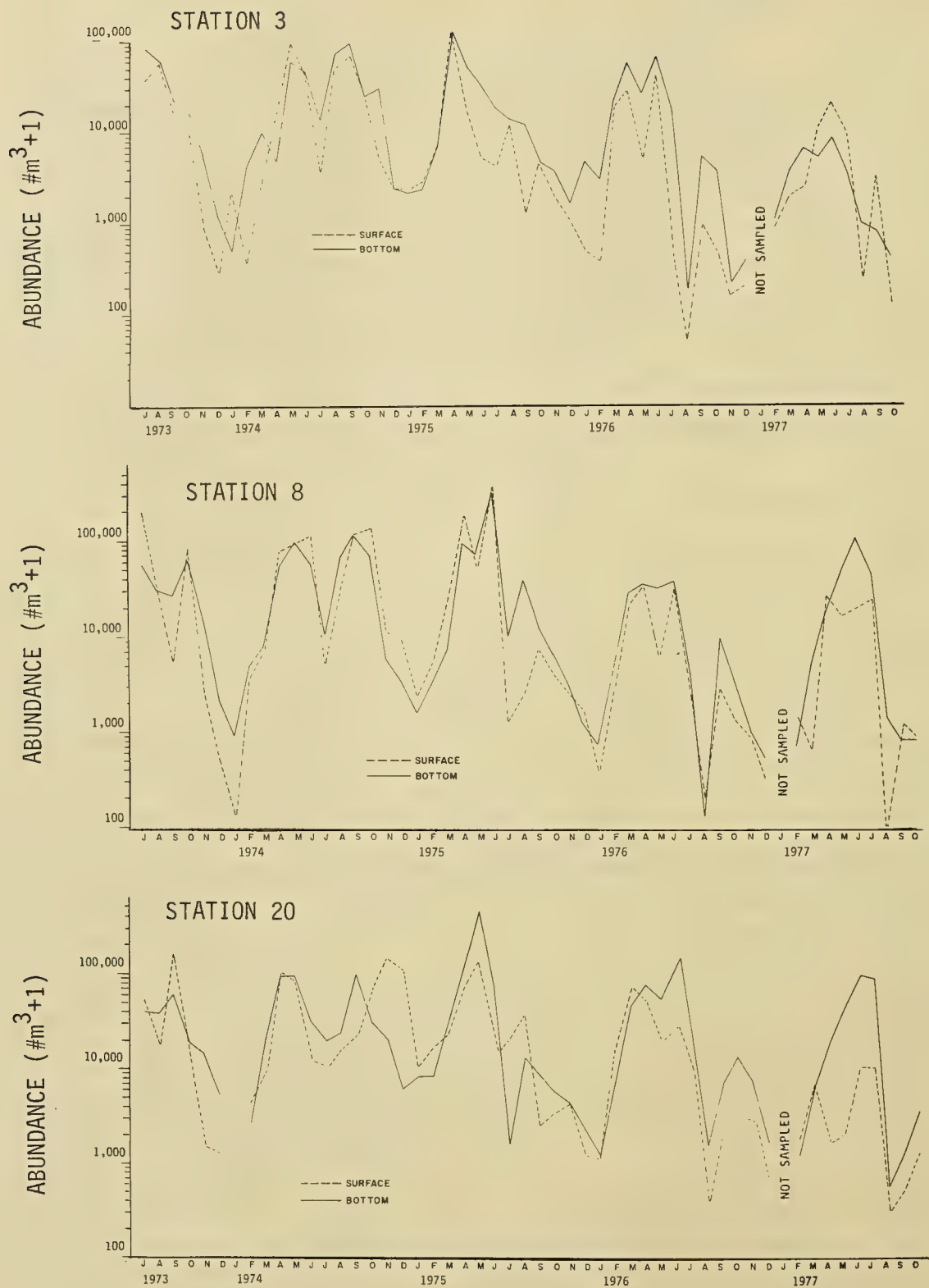


Figure 4-13. Total zooplankton ($\#m^3$) at Stations 3, 8 and 20 on surface and bottom (tides combined); July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

was made. Abundances usually remained at peak levels, with some fluctuations, through June, and declined by July (1974 and 1975) or August (1976 and 1977). Secondary abundance peaks, usually lower in magnitude than the initial late-spring/early summer peak, occurred from August through October 1974, in August 1975, from September through November 1976 and in September 1977. Although tidal and depth differences were occasionally apparent, seasonality appeared to exert the strongest influence on overall abundance estimates.

New Haven abundances were similar but slightly greater than those recorded at Millstone Point (Niantic Bay) (Figure 4-14). Seasonal abundance peaks occurred in the early summer at Millstone Point and declined precipitously in the winter as at New Haven Harbor (Figure 4-14). In Block Island Sound, Deevey (1952a) found total abundances similar to Millstone Point with an early summer maximum and winter decline (Figure 4-14c).

As in nearly all of the world's marine waters, the major component of the New Haven Harbor zooplankton were holoplankters, predominantly calanoid copepods (Figure 4-15). In New Haven Harbor, the dominant copepods were *Acartia tonsa* and *Acartia hudsonica* (= *clausi*) (Table 4-4). Together, these two congeners comprised the majority of the total zooplankton and as much as 93% of the calanoid copepod assemblage (Figure 4-14) (NAI, 1977; 1978). *A. hudsonica* normally exhibited a major population bloom in the spring while *A. tonsa* populations peaked in mid-to late summer; typically, when the density of one species was at a peak level, the other was virtually absent (Figure 4-16). Similar to the pattern observed in New Haven Harbor, total zooplankton species abundance peaks at Millstone Point coincided with *A. tonsa* and *A. hudsonica* peaks (Figure 4-14b). The successional pattern of *A. hudsonica* spring dominance/*A. tonsa* summer dominance was apparent at Millstone (Figure 4-14b). Conover (1956) and Jeffries (1962) were among the first to describe this successional relationship which generally prevails in most estuaries and embayments from Cape Cod to Cape Hatteras (Cronin *et al.*, 1962; Jeffries, 1964; Heinle, 1966; Sage and Herman, 1972).

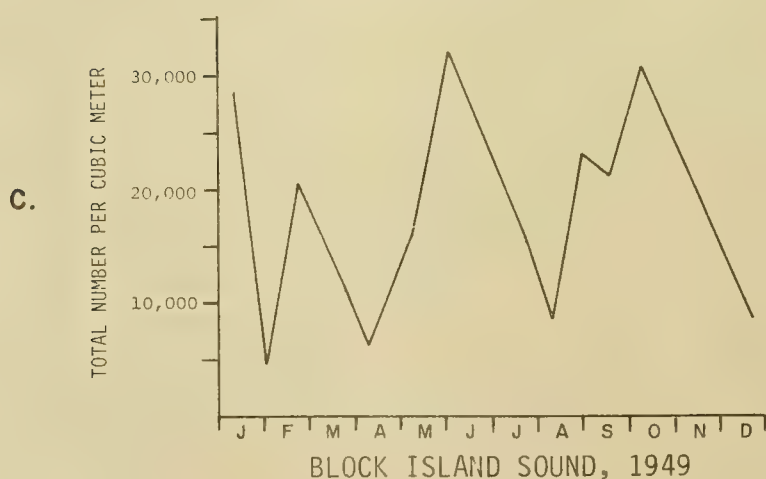
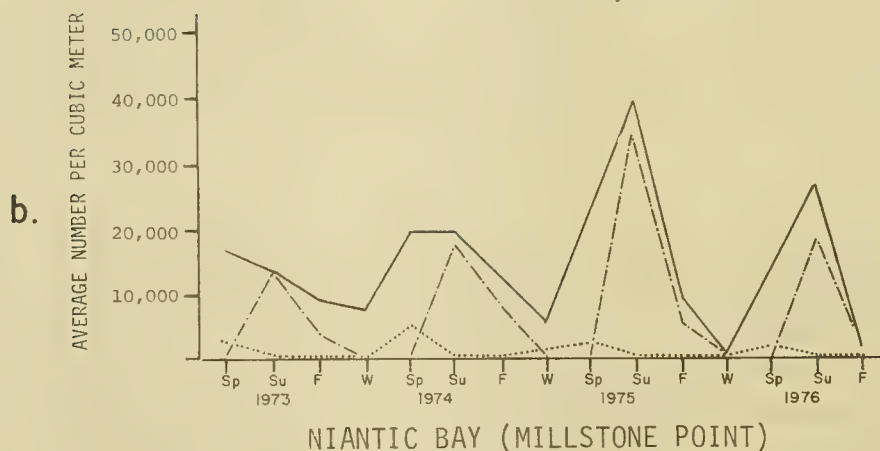
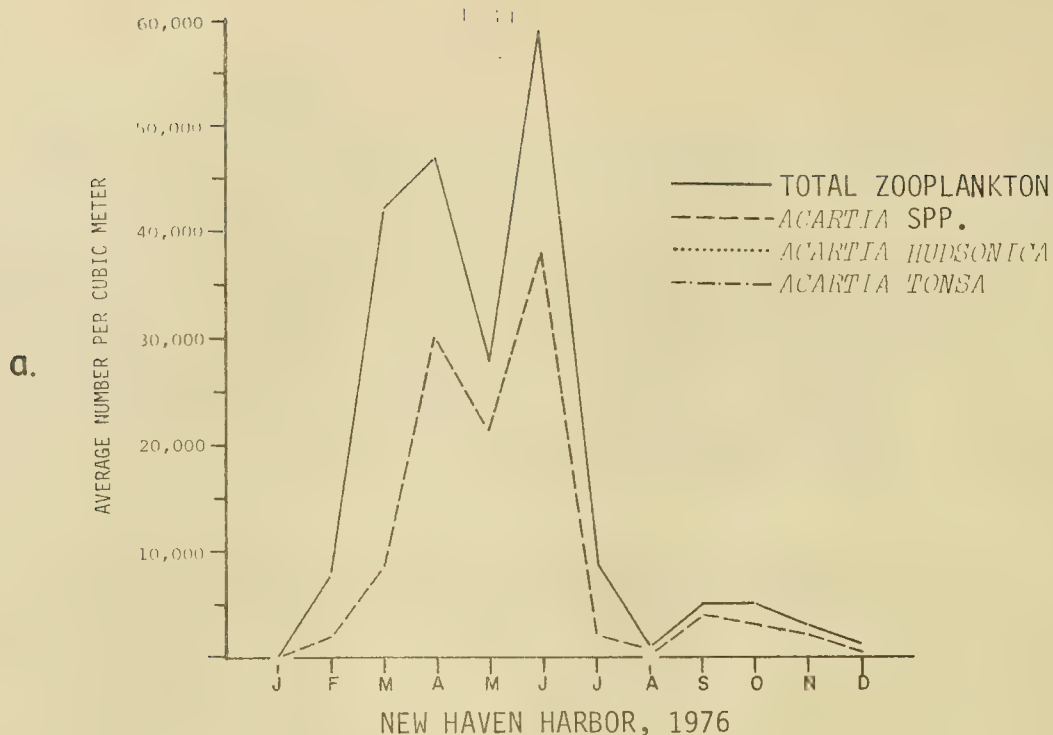


Figure 4-14. Numbers per cubic meter of total zooplankton organisms and *Acartia* spp. taken with a No. 10 net [333 μ m at Millstone] at a) New Haven Harbor, Stations 8 and 11 averaged, 1976; b) Niantic Bay, Millstone Stations 5 and 8 averaged, 1973-1976; c) Block Island Sound, 1949. New Haven Harbor Ecological Studies Summary Report, 1979.

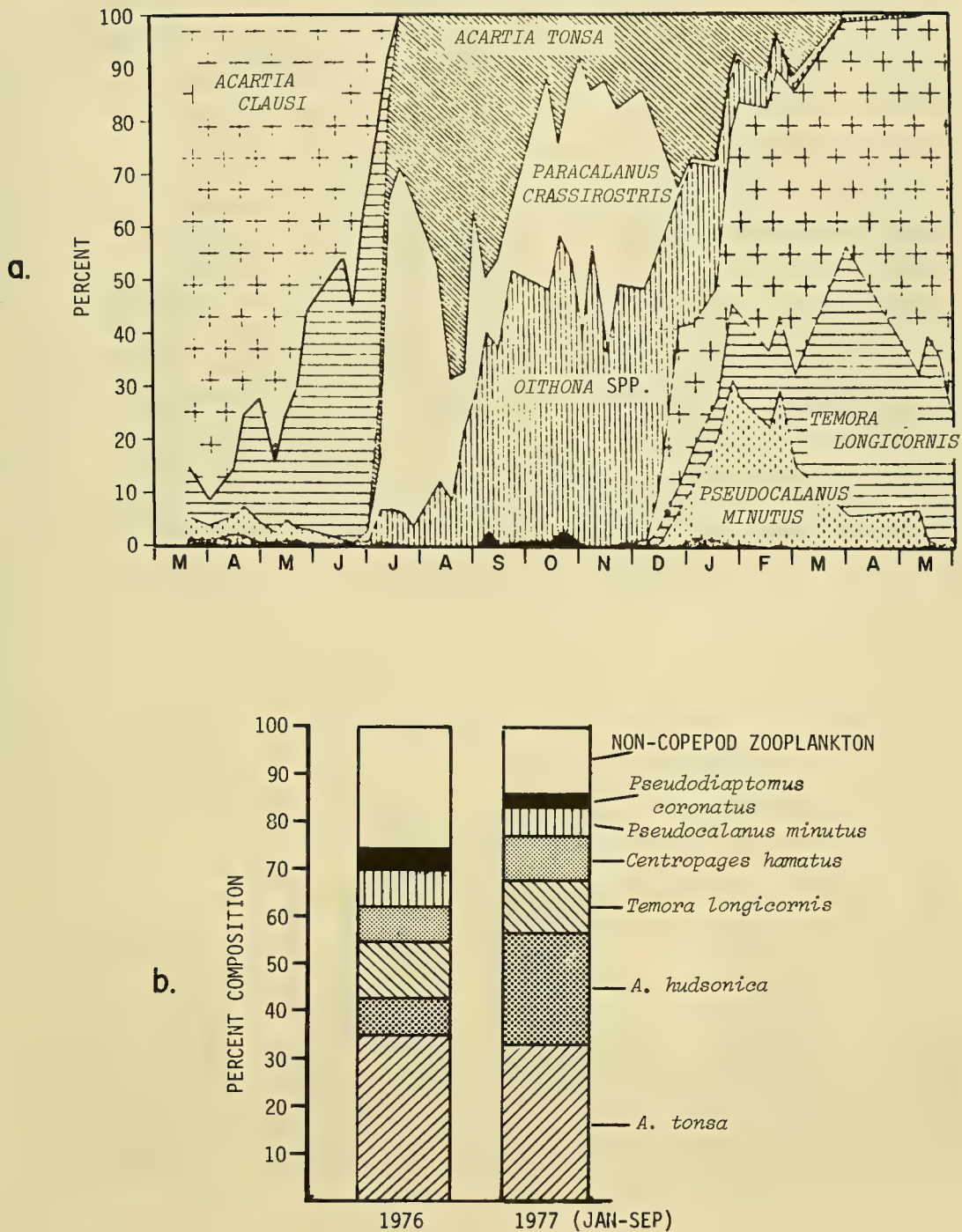


Figure 4-15. Relative percentages of important copepod species from a) Long Island Sound, March 1952 to June 1953 (from Deevey, 1956); b) Millstone Units I and II discharge, 1976 and 1977 [333 μ m net (from Battelle, 1978)]. New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 4-4. DOMINANT¹ ZOOPLANKTERS IN NEW HAVEN HARBOR FROM 1973 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	1973	1974	1975	1976	1977	BIOLOGICAL INDEX
Copepoda copepodites	9	9	10	10	10	48
Copepoda nauplii	10	10	9	8	7	44
Barnacle nauplii	8	8	5	7	8	36
<i>Acartia hudsonica</i>	0	7	8	9	9	33
<i>Acartia tonsa</i>	6	5	6	6	6	29
Polychaeta	7	6	2	4	1	20
<i>Oithona</i> spp.	2	4	7	5	0	18
Harpacticoida	5	2	0	0	4	11
Cyclopoida	0	1	4	2	0	7
Gastropod veligers	4	0	0	0	3	7
Bivalve veligers	3	3	0	0	0	6

¹ Determined by ranking individually within each year followed by ranking biological index values for each year as a whole.

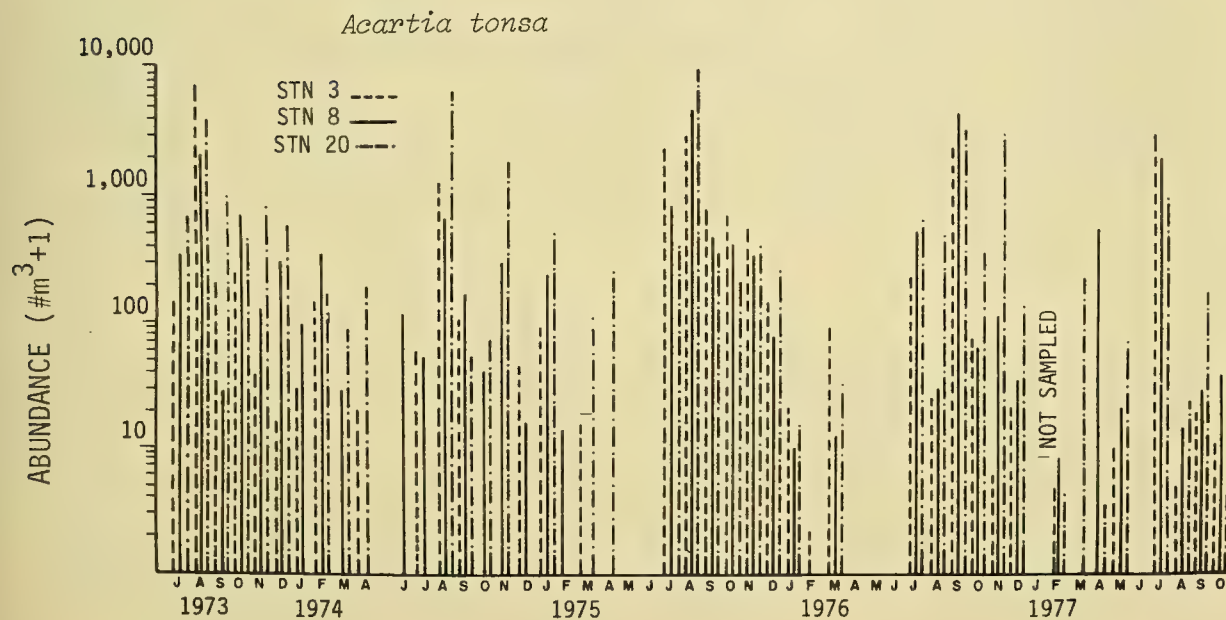
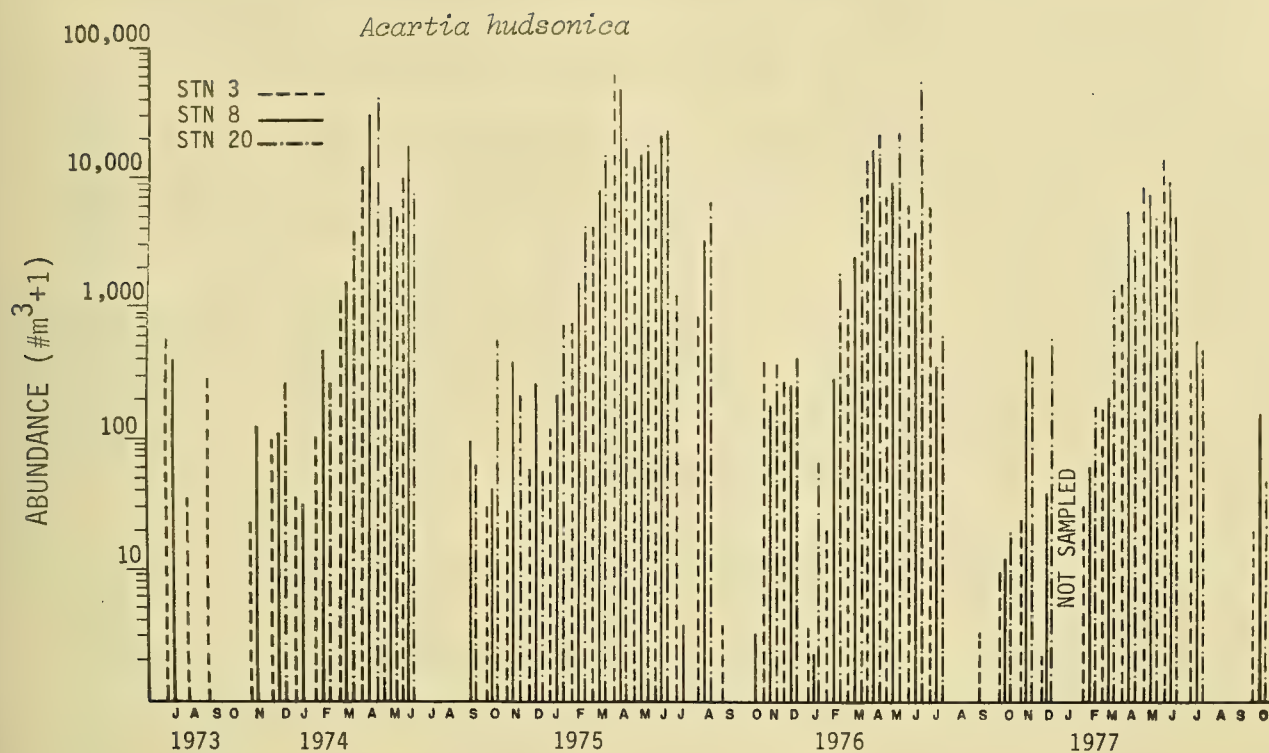


Figure 4-16. Abundance ($\#/\text{m}^3$) of *Acartia hudsonica* and *Acartia tonsa* at Stations 3, 8 and 20; July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Other calanoid species that exhibited substantial seasonal abundance peaks may be regarded as subdominants to the *Acartia* species. This subdominant category includes *Pseudodiaptomus coronatus* and *Pseudocalanus minutus*, which appear in most years to be prominent members of the New Haven Harbor zooplankton assemblage during colder months (November through April; Table 4-5). *Pseudodiaptomus coronatus* was also reported as a prominent copepod at Millstone Point (Figure 4-15b). *Pseudocalanus minutus* showed a similar pattern of winter dominance among copepods in greater Long Island Sound and comprised about the same proportion of total zooplankton at Millstone Point as at New Haven Harbor and Long Island Sound (Figure 4-15).

Abundance of *Temora longicornis* appears to have increased in recent years (Figure 4-17). In 1974, *T. longicornis* was present in New Haven Harbor zooplankton collections only from February through June. Peak abundance has typically occurred in late spring; maximum densities increased with each year. In 1977, *T. longicornis* became numerically the third most important copepod species and ranked sixth among all zooplankton categories differentiated. These recent findings are consistent with Long Island Sound and Millstone Point data which indicate *Temora longicornis* as a late spring dominant (Figure 4-15a) (Millstone 1973-1975). At Millstone, *Temora longicornis* comprised approximately the same proportion of the total zooplankton as seen by Deevey (1956) in Long Island Sound.

Predictably, early copepod developmental stages (i.e., nauplii and copepodites) outranked adult forms in numerical abundance (Table 4-4). Nauplii constitute the earliest of developmental stages and can reasonably be expected to have been far more abundant than copepodites (intermediate developmental stages) on a yearly average basis. That this was not reflected in the data (Figure 4-18) from 1975 through 1977 may be due to selective sampling of organisms of larger body size.

In addition to the calanoid copepod species discussed above, small cyclopoid copepods of the genus *Oithona* have occurred in New Haven

TABLE 4-5. MONTHLY RANKING* OF THE TEN MOST ABUNDANT ZOOPLANKTON TAXA (BASED ON MEAN OF ALL STATIONS AND BOTH TIDES FROM JULY 1973 THROUGH OCTOBER 1977). NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

1973														BI
	J	F	M	A	M	J	J	A	S	O	N	D		
Copepod nauplii							7	10	10	10	10	10	57	
Copepod copepodites							3	7	7	9	9	9	44	
Barnacle nauplii							9	5	9	7	8	5	43	
Polychaeta							8	9	8	8	6	0	39	
Acartia tonsa							1	8	3	5	7	8	32	
Harpacticoida							4	3	5	3	5	6	26	
Gastropod veligers							6	4	4	2	3	3	22	
Bivalve veligers							5	2	6	6	0	0	19	
Oithona spp.							0	1	2	4	4	0	11	
Tintinnidae							10	0	0	0	0	0	10	
Acartia hudsonica							0	0	0	0	2	7	9	
Barnacle cyprids							2	6	0	0	0	0	8	
Pseudodiaptomus coronatus							0	0	0	0	0	4	4	

1974														
	J	F	M	A	M	J	J	A	S	O	N	D	BI	
Copepod nauplii	10	10	10	8	10	7	9	9	10	10	10	10	113	
Copepod copepodites	8	9	8	9	8	4	4	7	8	7	9	9	90	
Barnacle nauplii	1	8	6	0	9	8	7	4	7	8	8	5	71	
Acartia hudsonica	6	7	9	10	6	9	0	0	0	1	4	7	59	
Polychaeta	0	0	0	0	5	10	10	10	9	9	3	0	56	
Acartia tonsa	7	6	2	0	0	0	2	8	0	2	7	8	42	
Oithona spp.	2	4	5	4	0	0	0	0	3	5	5	2	30	
Bivalve veligers	0	0	0	0	7	5	8	0	6	4	0	0	30	
Harpacticoida	5	3	3	7	3	1	0	0	0	0	0	4	26	
Cyclopoida	0	0	0	0	0	0	3	3	2	6	6	6	26	
Gastropod veligers	0	0	0	0	0	3	6	6	4	3	2	0	24	
Pseudocalanus minutus	3	5	7	6	0	0	0	0	0	0	0	0	21	
Rotifera	9	0	4	0	0	0	0	5	0	0	0	3	21	

1975														
	J	F	M	A	M	J	J	A	S	O	N	D	BI	
Copepoda copepodites	9	8	8	8	10	7	10	10	10	10	10	10	110	
Copepoda nauplii	10	9	9	10	9	1	4	7	9	8	8	8	92	
<i>Acartia hudsonica</i>	7	10	10	9	8	9	3	8	0	1	7	9	81	
<i>Oithona</i> spp.	6	7	5	3	0	0	6	6	8	6	4	5	56	
<i>Acartia tonsa</i>	8	0	0	0	0	0	9	9	6	7	9	7	55	
Barnacle nauplii	2	4	2	0	6	10	1	3	7	9	3	3	50	
Cyclopoida	5	0	3	4	7	0	2	5	5	5	5	6	47	
Gastropoda	0	0	0	0	0	8	8	4	4	3	1	0	28	
Polychaeta	0	0	1	0	5	4	7	1	3	3	0	0	20	

* 10 was most abundant taxon, 1 was 10th most abundant, 0 signifies ranking not among top 10 organisms

Continued

TABLE 4-5. (Continued)

1976													
	J	F	M	A	M	J	J	A	S	O	N	D	BI
Copepoda copepodites	7	9	9	9	9	8	1	0	0	10	6	4	72
<i>Acartia hudsonica</i>	2	8	8	10	10	10	3	0	0	0	9	10	70
Copepoda nauplii	8	10	10	7	6	2	8	3	6	3	1	2	66
Barnacle nauplii	4	2	6	5	7	9	0	8	7	5	0	5	58
<i>Acartia tonsa</i>	0	0	0	0	0	0	7	10	10	6	10	9	52
<i>Oithona</i> spp.	9	3	0	1	2	0	6	0	4	7	8	7	47
Polychaeta	0	7	7	4	4	4	5	7	3	1	4	0	46
<i>Pseudocalanus minutus</i>	0	0	0	3	0	0	2	0	8	9	7	3	32
Cyclopoida	6	5	1	0	5	3	0	0	0	8	2	0	30
<i>Pseudodiaptomus coronatus</i>	5	4	0	0	0	0	0	1	5	4	3	8	30
Harpacticoida	3	1	0	2	8	6	0	0	0	0	0	6	26
Gastropod veligers	0	0	0	0	1	7	4	6	2	2	0	0	22
Barnacle cyprids	0	0	5	0	0	0	9	9	1	0	0	0	24

1977													
	J	F	M	A	M	J	J	A	S	O	N	D	BI
Copepoda copepodites		5	7	10	10	10	9	8	9	10			78
<i>Acartia hudsonica</i>		7	8	9	9	8	3	0	0	9			53
Barnacle nauplii		9	1	0	4	7	7	9	10	0			47
Copepoda nauplii	NOT SAMP LED	10	9	3	5	0	0	1	6	2			36
<i>Acartia tonsa</i>		0	0	5	3	0	8	4	7	7			34
<i>Temora longicornis</i>		3	4	8	8	9	0	0	0	0			32
Harpacticoida		8	6	7	7	4	0	0	0	0			32
Gastropod veligers		0	0	0	0	6	5	10	4	1			26
Barnacle cyprids		0	5	4	0	0	6	7	3	0			26
Polychaeta		6	10	0	1	3	4	0	0	0			24
Cyclopoida		0	0	0	0	0	0	5	8	8			21
<i>Pseudocalanus minutus</i>		0	2	2	6	5	0	0	0	4			19

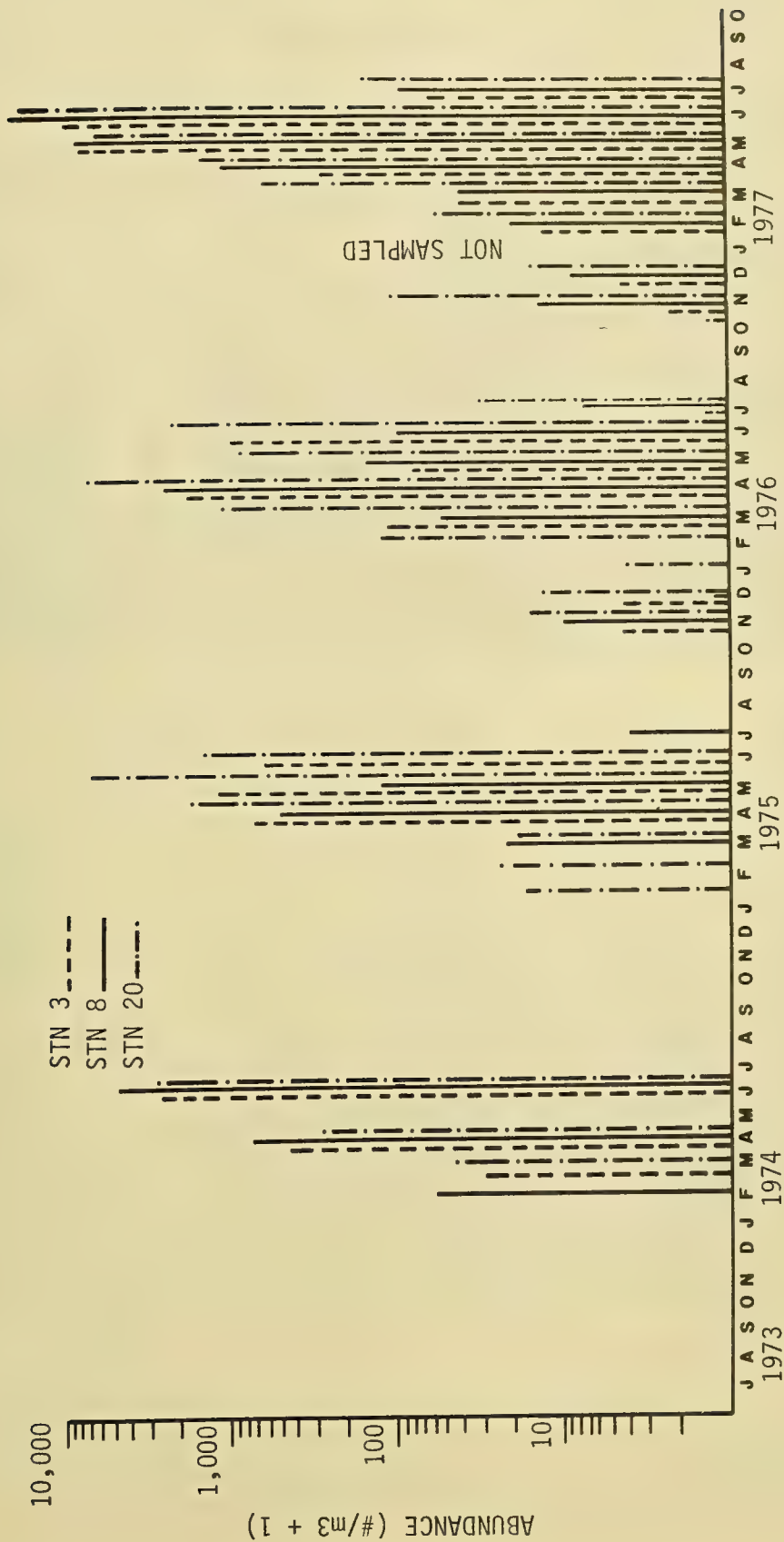


Figure 4-17. Abundance (#/m³) of *Temora longicornis* at Stations 3, 8 and 20; July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

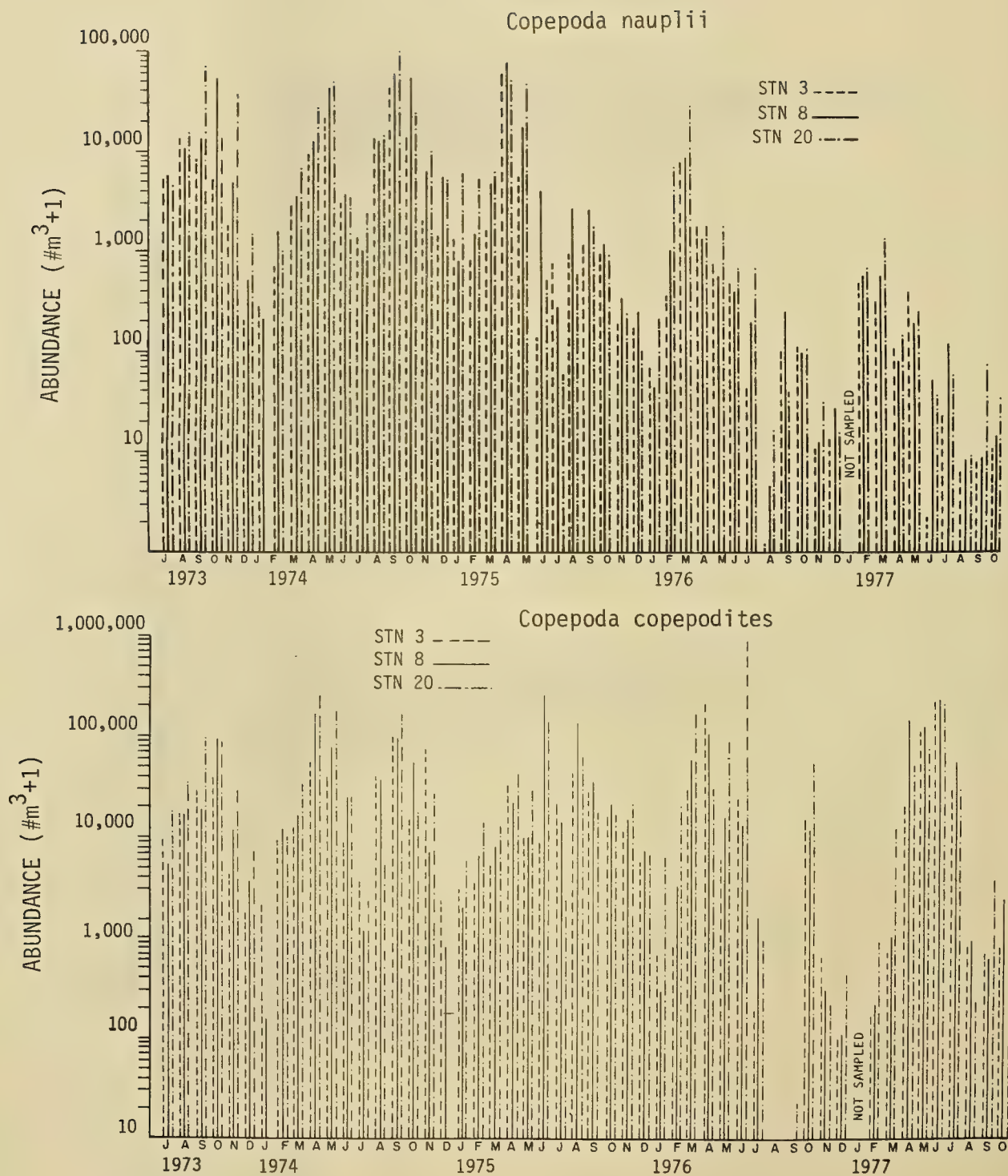


Figure 4-18. Abundance ($\#m^3$) of Copepoda nauplii and copepodites at Stations 3, 8 and 20; July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Harbor on a fairly regular and essentially year-round basis. *Oithona* sp(p). was, however, relatively scarce in 1977 collections (Table 4-5).

Deevey (1952a) reported *Oithona* sp. as a year round constituent of Block Island Sound plankton which comprised a large percent of the fall copepods (Figure 4-15). *Oithona* sp. was not reported at Millstone Point, probably because of the larger net size used (333 μ m vs 158 μ m net at New Haven and Long Island Sound).

Important members of the invertebrate meroplankton assemblage in New Haven Harbor included pelagic larvae of barnacles, gastropods, polychaete worms, and bivalve molluscs (Table 4-4). Among the meroplankters, barnacle larvae consistently ranked highest in abundance (Table 4-4). Judging from sessile adult abundance, the species represented have been primarily *Balanus eburneus* and *B. improvisus*. A poly-modal pattern of seasonal abundance is suggested in Figure 4-19 and presumably represents successive spawning episodes. Peaks of reproductive activity appeared to be May-July and September-October, with a third, relatively modest, population peak occurring in February-March. In the case of barnacle cyprids (a later developmental stage), there appeared to be essentially two abundance peaks per year (Figure 4-19), the first occurring in March or April and the second from June through August. These peaks corresponded to the February-March and May-July naupliar population peaks. There appears to have been no cyprid peak corresponding to the September naupliar peak perhaps due to: 1) onset of winter and consequent scarcity of food, and/or 2) encounter with particular predators, such as ctenophores that have occurred in substantial quantities during the months of August and September (NAI, 1978). Deevey (1952a) reported *Balanus* sp. larvae in Block Island Sound from January through April.

Polychaete larvae ranked close to barnacle larvae in overall numerical importance (Table 4-4) particularly in 1973 and 1974 when data were derived from a Clarke-Bumpus net (76 μ m mesh). During 1975, 1976 and 1977, after a summer peak, there was a decline in abundance (Figure

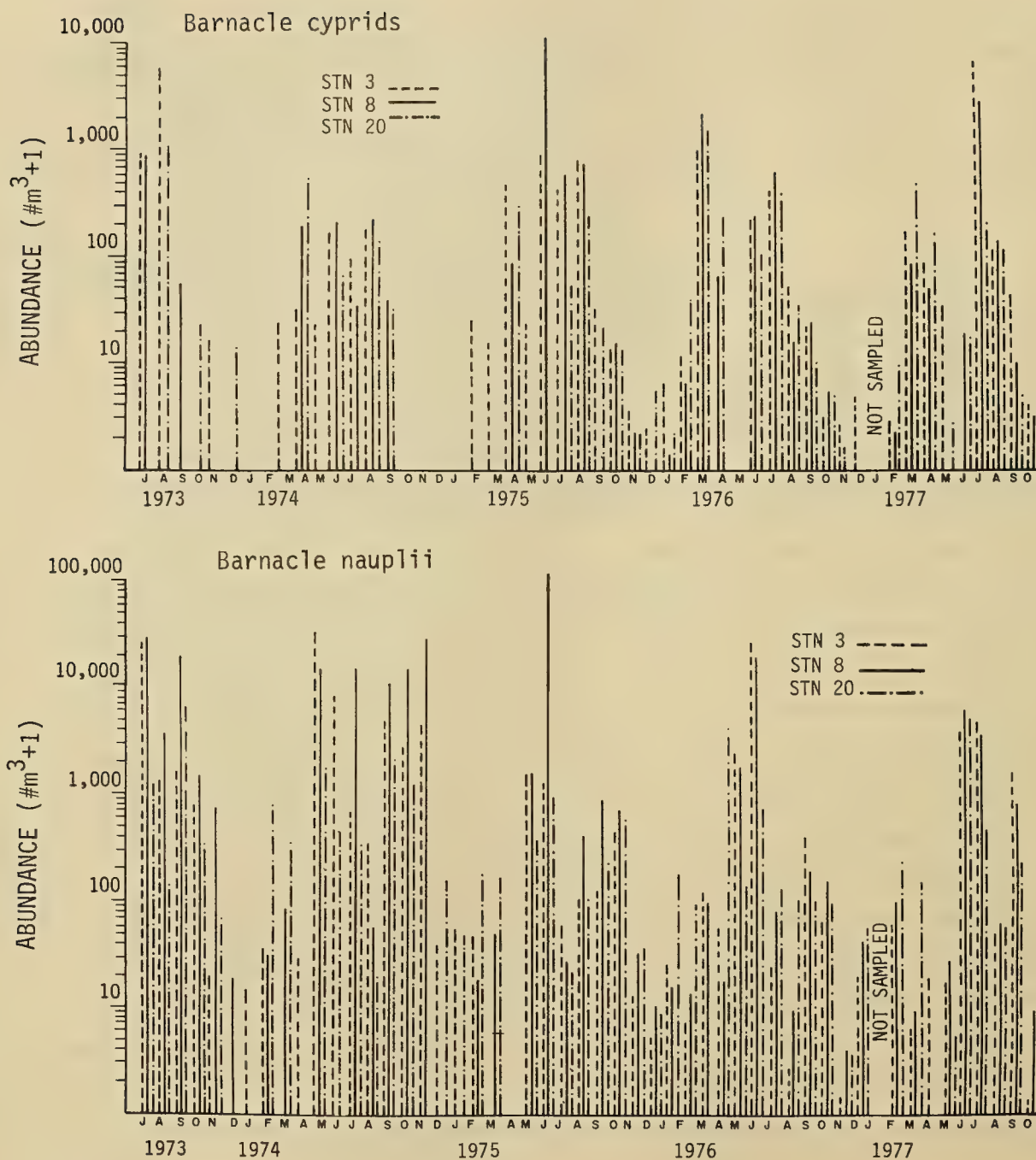


Figure 4-19. Abundance ($\#m^3$) of Barnacle cyprids and nauplii at Stations 3, 8 and 20; July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

4-20). This difference may be the result of the net change, i.e., small newly hatched larvae captured in earlier years by the 76 μ m CB net may have been undersampled by the larger mesh, 15 μ m 1/2-meter net. These small larvae were probably most prevalent in early to late summer and early fall months. Deevey (1952a) reported polychaete larvae in spring Block Island Sound plankton samples. It may be reasonably assumed that a great many taxa comprise the polychaete group with no one taxon predominating on a yearly basis.

Veliger larvae of gastropod and bivalve molluscs occurred primarily during warmer months in New Haven Harbor (May through November) and in Long Island Sound (Deevey, 1952a). Again, body-size selectivity of the larger mesh net appears to be the most likely explanation for changes in ranking regarding the bivalves (Table 4-4) and for changes in the appearance of seasonal population fluctuation patterns comparing 1973 and 1974 with 1975 through 1977 data for both gastropods and bivalves (Figure 4-21). The most abundant gastropod veliger was probably *Littorina* spp.; from close examination of a few samples, *Mytilus edulis* and *Mya arenaria* were the predominant bivalve larvae. Larvae of the American oyster (*Crassostrea virginica*) probably comprised a small but important fraction of the bivalve assemblage in mid-July, with peak densities of 10 to 70 larvae per m³ during 1977 (NAI, 1978). Though these densities of oyster larvae are unexceptional in Long Island Sound (Loosanoff and Engel, 1940), because of the temporal nature of peaks in oyster larvae, data from monthly sampling cannot be assumed to give representative data on oyster larvae densities.

Of the major tychoipelagic forms represented in New Haven Harbor zooplankton collections, only harpacticoid copepods ranked relatively high in overall abundance (Table 4-4). As in the case of polychaete and gastropod larvae, a sharp summer reduction in numbers following a late spring peak was observed during the years 1975 through 1977 (Figure 4-22). No summer decline was indicated in 1973. In 1974, however, harpacticoids disappeared completely from Clarke-Bumpus collections during July and August.

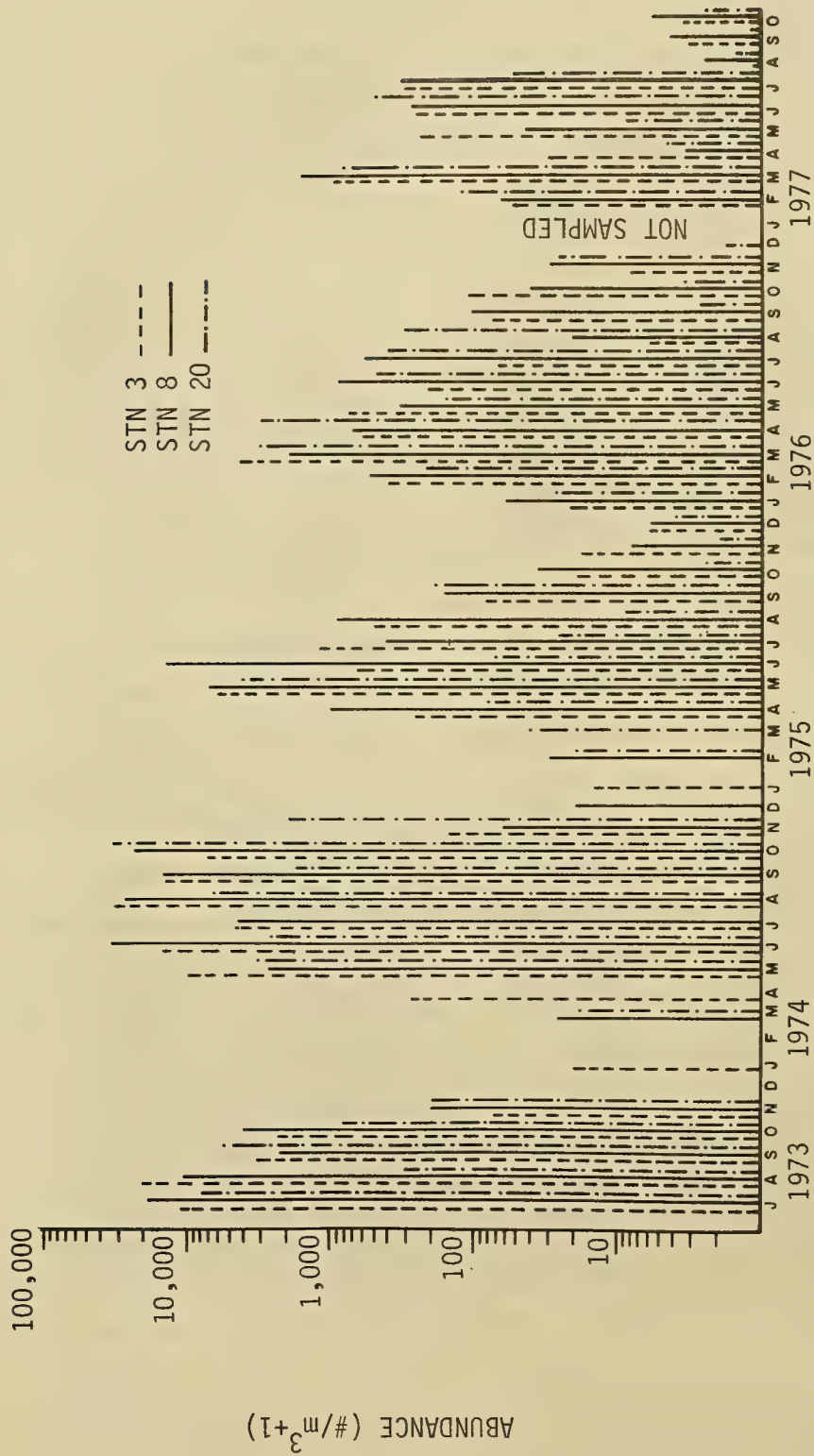


Figure 4-20. Abundance (#/m³) of Polychaeta larvae at Stations 3, 8 and 20; July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

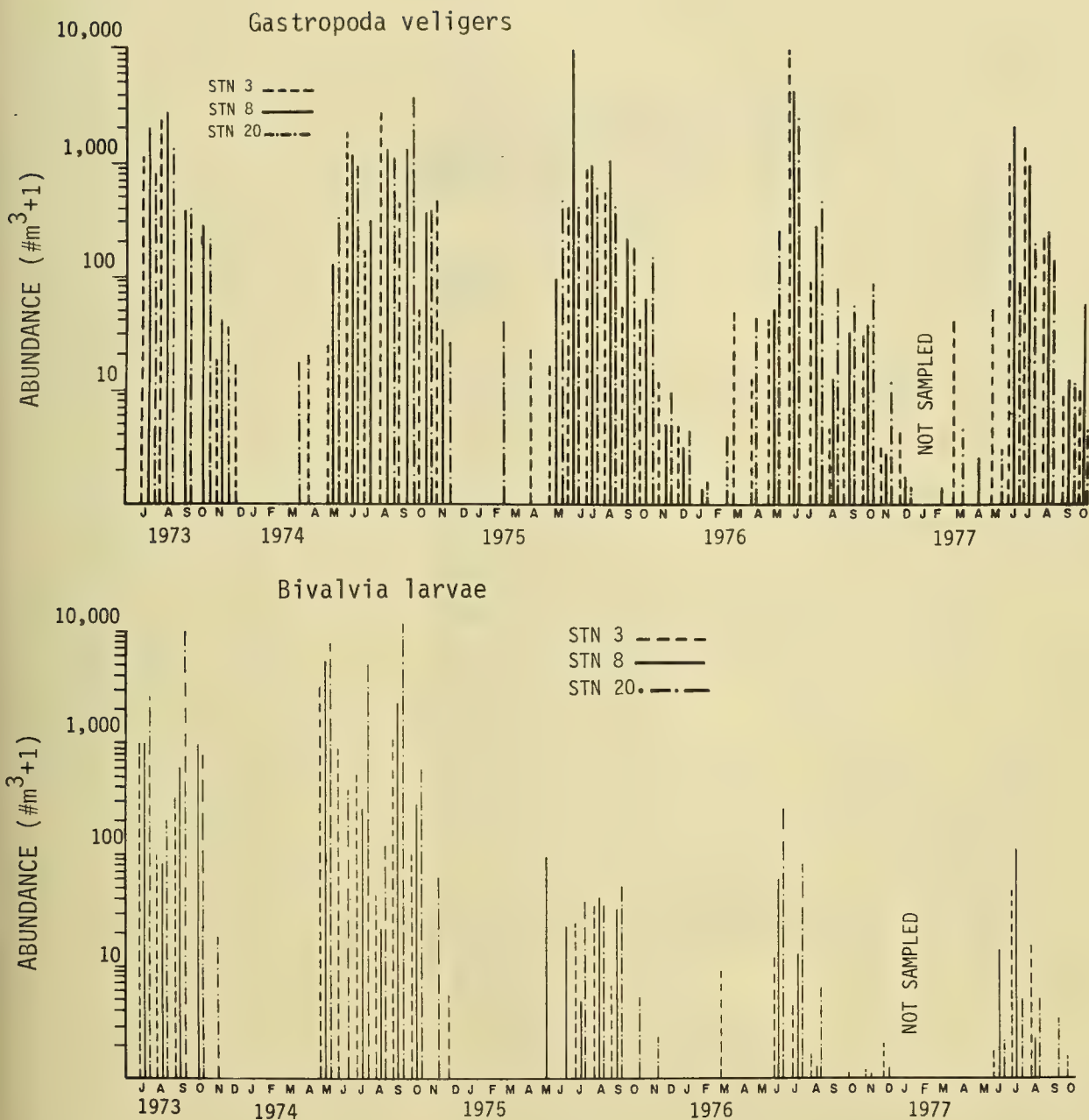


Figure 4-21. Abundance ($\#/\text{m}^3$) of Gastropoda veligers and Bivalve larvae at Stations 3, 8 and 20; July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

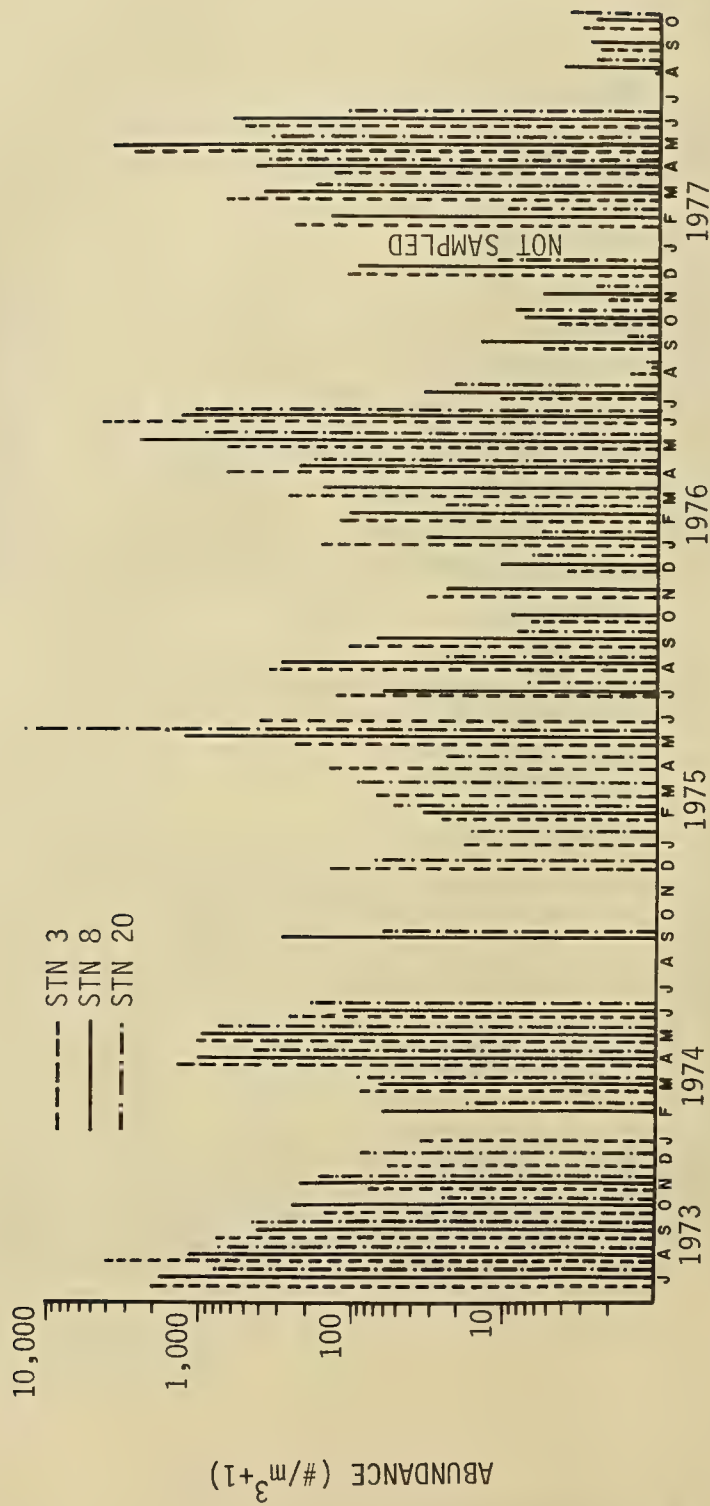


Figure 4-22. Abundance ($\#/m^3$) of Harpacticoida at Stations 3, 8 and 20; July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

In summary, the winter months (December through February) represented a period of low zooplankton productivity. Earliest reproductive response to the onset of spring conditions was typically found among the ranking calanoid copepod species (particularly *Acartia hudsonica*) and barnacles (i.e., *Balanus* sp(p).). Late spring and early summer was a period of particularly intense reproductive activity for many benthic invertebrates including barnacles, polychaetes, bivalves and gastropods. Production of planktonic larvae continued throughout the summer: as indicated by CB sample results smaller-bodied forms reached maximum abundances and dominated plankton samples during the warmest months of the year (July and August). Among the holoplankters, *Acartia tonsa* usually became dominant during mid- to late summer. In autumn, the winter faunal assemblage, consisting of calanoid copepods and barnacle larvae, returned to prominence. The New Haven Harbor plankton assemblage is consistent in composition and seasonal distribution with that seen in greater Long Island Sound and nearby harbors.

Ichthyoplankton

Of the more than 45 ichthyoplankton taxa identified in New Haven Harbor from 1974 through 1977 (Appendix Table 4-2), the dominant forms (Table 4-6) were generally similar to those reported from Long Island Sound and adjacent waters from 1943 through 1975 (Tables 4-7 and 4-8). These dominant species included *Anchoa* spp. and Labrid/*Limanda* eggs, and *Anchoa* spp. and *Ammodytes* larvae. Taxa dominant as adults and juveniles in seine, trawl, and gill net collections made as part of the Harbor Station monitoring program (Section 11.0) and Warfel and Merri-man's seine collections (1944), but not important in ichthyoplankton collections, included *Menidia menidia*, *Fundulus* spp., *Brevoortia tyrannus*, *Sphaeroides maculatus*, *Osmerus mordax*, *Microgadus tomcod* and *Alosa* spp. These predominantly shorezone species largely spawn in areas adjacent to the harbor proper (freshwater reaches of the estuary and intertidal beaches) which were not sampled for ichthyoplankton; the absence of these species in the ichthyoplankton sampled does not indicate inability to spawn in the area.

TABLE 4-6. NUMERICALLY DOMINANT (>1%) FISH EGGS AND LARVAE COLLECTED FROM NEW HAVEN HARBOR FROM 1974 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

FISH EGGS

<u>1974</u>	<u>1975</u>
1. Labrid/ <i>Limanda</i> (97.5)	1. <i>Anchoa</i> spp. (39.9)
2. <i>Anchoa</i> spp. (2.4)	2. <i>Scomber scombrus</i> (28.8)
	3. Labrid/ <i>Limanda</i> (26.5)
	4. Unidentified (2.0)
<u>1976</u>	<u>1977</u>
1. <i>Anchoa</i> spp. (51.3)	1. <i>Anchoa</i> spp. (90.8)
2. Labrid/ <i>Limanda</i> (28.5)	2. Labrid/ <i>Limanda</i> (4.9)
3. <i>Urophycis/Enchelyopus/Peprilus</i> (8.5)	3. <i>Scophthalmus/Paralichthys</i> (1.8)
4. <i>Scomber scombrus</i> (2-3)	

FISH LARVAE

<u>1974</u>	<u>1975</u>
1. <i>Anchoa</i> spp. (99.2)	1. <i>Anchoa</i> spp. (95.6)
	2. <i>Ammodytes americanus</i> (1.5)
<u>1976</u>	<u>1977</u>
1. <i>Anchoa</i> spp. (87.8)	1. <i>Anchoa</i> spp. (93.1)
2. <i>Myoxocephalus</i> (2.9)	2. <i>Ammodytes americanus</i> (3.1)
3. <i>Pseudopleuronectes americanus</i> (2.8)	3. <i>Pseudopleuronectes americanus</i> (1.5)
4. <i>Cynoscion regalis</i> (2.3)	
5. <i>Ammodytes americanus</i> (2.0)	

Numbers in parentheses are percent composition

TABLE 4-7. DOMINANT SPECIES OF FISH EGGS REPORTED FROM LONG ISLAND SOUND AND ADJACENT WATERS FROM 1943 THROUGH 1975. NEW HAVEN HARBOR ECOLOGICAL STUDY SUMMARY REPORT, 1979.

Merriman and Sclar (1952)
Block Island Sound, 1943-1946

1. *Cynoscion regalis*
2. *Tautogolabrus adspersus*
3. *Peprilus (Poronotus) spp.*
4. *Gadus morhua*
5. *Scomber scombrus*

Wheatland (1956)
Long Island Sound, 1952-1954

1. *Anchoa mitchilli*
2. *Tautogolabrus adspersus*
3. *Brevoortia tyrannus*
4. *Enchelyopus cimbrius*
5. *Scophthalmus (Lophopsetta) aquosus*

Richards (1959)
Long Island Sound, 1954-1955

1954

1. *Anchoa mitchilli*
2. *Tautogolabrus adspersus*
3. *Tautoga onitis*
4. *Enchelyopus cimbrius*
5. *Scophthalmus (Lophopsetta) aquosus*

1955

1. *Anchoa mitchilli*
2. *Enchelyopus cimbrius*
3. *Tautogolabrus adspersus*
4. *Tautoga onitis*
5. *Stenotomus chrysops*

Herman (1963)
Narragansett Bay, R.I., 1957

1. *Tautogolabrus adspersus*
2. *Tautoga onitis*
3. *Brevoortia tyrannus*
4. *Prionotus evolans*
5. *Stenotomus chrysops*
6. *Scophthalmus aquosus*

Pearcy and Richards (1962)
Mystic River, Conn., 1958-1960

1. Labridae
2. *Pseudopleuronectes americanus*

Williams (1968)
Long Island Sound

1. *Enchelyopus cimbrius*
2. *Scophthalmus aquosus*
3. *Tautogolabrus adspersus*
4. *Anchoa mitchilli*
5. *Brevoortia tyrannus*
6. *Tautoga onitis*
7. *Prionotus spp.*

Northeast Utilities (1976)
Millstone Point, 1971-1975

1. Labrid/Limanda
2. *Scomber scombrus*
3. *Anchoa mitchilli*
4. *Brevoortia tyrannus*
5. *Prionotus spp.*

TABLE 4-8. DOMINANT SPECIES OF FISH LARVAE REPORTED FROM LONG ISLAND SOUND AND ADJACENT WATERS FROM 1943 THROUGH 1975. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

Merriman and Sclar (1952)
Block Island Sound, 1943-1946

1. *Cynoscion regalis*
2. *Tautogolabrus adspersus*
3. *Urophycis* spp.
4. *Limanda ferruginea*
5. *Myoxocephalus* spp.

Wheatland (1956)
Long Island Sound, 1952-1954

1. *Anchoa mitchilli*
2. *Ammodytes americanus*
3. *Brevoortia tyrannus*
4. *Pseudopleuronectes americanus*

Richards (1959)
Long Island Sound, 1954-1955

1954

1. *Anchoa mitchilli*
2. *Brevoortia tyrannus*
3. *Pseudopleuronectes americanus*
4. *Cynoscion regalis*
5. *Ammodytes americanus*

1955

1. *Ammodytes americanus*
2. *Anchoa mitchilli*
3. *Brevoortia tyrannus*
4. *Pseudopleuronectes americanus*
5. *Tautogolabrus adspersus*

Herman (1963)
Narragansett Bay, R.I., 1957

1. *Myoxocephalus* spp.
2. *Ammodytes americanus*
3. *Tautogolabrus adspersus*
4. *Anchoa mitchilli*
5. *Menidia menidia*

Pearcy and Richards (1962)
Mystic River, Conn., 1958-1960

1. *Pseudopleuronectes americanus*
2. *Microgadus tomcod*
3. *Myoxocephalus aeneus*
4. *Anchoa mitchilli*
5. *Pholis gunnellus*

Northeast Utilities (1976)
Millstone Point, Conn., 1971-1975

1. Engraulidae
2. *Scomber scombrus*
3. *Tautogolabrus adspersus*
4. *Tautoga onitis*
5. *Pseudopleuronectes americanus*
6. *Scophthalmus aquosus*

Anchoa spp. eggs and larvae (representing pooled Engraulidae, *Anchoa* spp., *A. mitchilli*, and *A. hepsetus*) were selected for detailed discussion because they comprised the most abundant taxon during the 1974-1977 study period and because they have been historically dominant in the area (Tables 4-6, 4-7 and 4-8). It is assumed that *A. mitchilli* is the predominant species, since the majority of ichthyoplankton and fisheries investigations conducted between Sandy Hook, New Jersey, and Long Island Sound have failed to collect any *A. hepsetus* (Warfel and Merriman, 1944; Merriman and Sclar, 1952; Wheatland, 1956; Richards, 1959; Herman, 1963; Croker, 1965). Bigelow and Schroeder (1953) noted that *A. hepsetus* is most common from Chesapeake Bay south^{*}.

Cynoscion regalis and *Pseudopleuronectes americanus* were selected because they are important to recreational and commercial fisheries in the study area. *C. regalis* spawns in Long Island Sound (Warfel and Merriman, 1944; Wheatland, 1956; Richards, 1959), while *P. americanus* spawns in estuaries (Pearcy, 1962) between Labrador and Georgia (Leim and Scott, 1966). Both species utilize New Haven Harbor as a nursery area (Warfel and Merriman, 1944).

Labrid/*Limanda* and *Urophycis/Enchelyopus/Peprilus* egg types were selected because they were relatively abundant and constitute the reproductive products of species common to the area (see Section 11.0). Labrid/*Limanda* eggs are morphologically difficult to distinguish (Wheatland, 1956; Merriman and Sclar, 1952). This group is considered to be virtually all Labrid eggs (*Tautogolabrus adspersus* and/or *Tautoga onitis*), since adults of both species are locally abundant while *Limanda ferruginea* is relatively rare (see Section 11.0). *L. ferruginea* spawning appears to be concentrated offshore, since no eggs have been identified in several previous surveys of Long Island Sound (Wheatland, 1956; Richards, 1959; Herman, 1963) or Block Island Sound (Merriman and

* Specimens of *A. hepsetus* have been collected in New Haven Harbor (see Section 11.00, in Long Island Sound near Shoreham (a single specimen) by Zawacki and Briggs (1976), and in the Mystic River, Connecticut (Pearcy and Richards, 1962), while both eggs and adults have been identified from collections near the Millstone Point Nuclear Generating Station (Northeast Utilities Service Company, 1976).

Sclar, 1952) and larvae have generally been rare. The Labrid/*Limanda* egg type has been common near the Millstone Point Nuclear Generating Station; these eggs also appear to be primarily Labrids (Northeast Utilities Service Company, 1976).

Urophycis/Enchelyopus/Peprilus eggs are also difficult to distinguish from one another. Of the three component genera, *Peprilus triacanthus* probably contributes least to this group since spawning is apparently concentrated more offshore (Wheatland, 1956; Austin, 1976), although *Peprilus* eggs have been collected from Millstone Point (Northeast Utilities Service Company, 1976) and Narragansett Bay (Herman, 1963). The majority of this egg type is probably *Enchelyopus cimbrius* since other investigators found them relatively abundant in the Long Island Sound Area (Table 4-7), while *Urophycis* and *Peprilus* eggs were generally unimportant.

In New Haven Harbor from 1974 through 1977, total fish egg abundance generally peaked during June and July (Table 4-9) when *Anchoa* spp. eggs predominated (Figure 4-23); *Scomber scombrus* eggs, however, comprised a major fraction during May 1975. Fish-egg abundance was relatively low between August and April of each year (Table 4-9). Generally, fish egg densities were higher at Stations 18 and 20 from 1974 through 1976, while during 1977 fish eggs were more abundant at Stations 8 and 11 (Table 4-9). Dominant taxa were Labrids (1974-1976), *Anchoa* spp. (1976, 1977), and *S. scombrus* (1975) (Table 4-10). Although sample collection only occurred monthly and preoperational (prior to August 1975) data are limited, seasonality of the dominant taxa did not appear to vary much over the four-year study period (Figure 4-23). Inter-year variation of dominants was consistent over all stations (Table 4-10). Inter-year variation in fish-egg abundance (Table 4-9) was consistent with the inter-year variability found by other investigators in the Long Island Sound area and is discussed below.

Fish larvae were most abundant during July and August of each year when *Anchoa* spp. predominated (Table 4-9; Figure 4-24). In addition

(Text continued on page 4-59)

TABLE 4-9. MEAN ABUNDANCE ($\#/m^3$) OF TOTAL FISH EGGS AND LARVAE COLLECTED FROM NEW HAVEN HARBOR FROM 1974 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

a. MONTHLY MEANS (MEAN OF ALL STATIONS EXCLUDING STATION 11)

FISH EGGS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	---	---	---	---	---	---	2.458	.758	.003	0	0	0
1975	0	.004	.022	.248	20.392	25.762	.192	1.160	.008	0	0	0
1976	0	0	.778	3.028	6.613	13.510	25.234	1.802	.098	.003	<.001	0
1977	---	.002	.002	.729	6.814	37.860	114.590	.612	.027	.007	---	---

FISH LARVAE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	---	---	---	---	---	---	.275	4.779	.016	.005	0	.001
1975	.106	.013	.042	.299	.052	.149	11.286	1.958	.036	.009	.029	.001
1976	.001	.020	.238	.523	.019	.084	8.091	.433	.116	.001	.001	.003
1977	---	.017	.172	1.017	.078	.292	23.406	.893	.015	.026	---	---

b. STATION MEANS (MEAN OF ALL DATES)

FISH EGGS

	STA 3	STA 6	STA 8	STA 11	STA 18	STA 20
1974	.254	.077	.621	---	.635	1.090
1975	2.330	3.104	2.390	5.116	5.270	7.341
1976	.611	.461	1.722	1.693	9.059	11.980
1977	9.349	8.308	28.480	25.420	19.130	16.460

FISH LARVAE

	STA 3	STA 6	STA 8	STA 11	STA 18	STA 20
1974	.455	.135	.346	---	.933	2.399
1975	1.729	.680	.464	2.455	1.568	.865
1976	.376	.343	.313	1.161	.327	2.250
1977	5.250	.573	2.128	2.672	1.733	4.901

--- = No samples collected

TABLE 4-10. DOMINANT (>20%) FISH EGGS AND LARVAE, AND PERCENT COMPOSITION BY STATION IN NEW HAVEN HARBOR FROM 1974 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

EGGS	STATION						
	YEAR	3	6	8	11	18	20
EGGS	1974	Labrid (99.7)	Labrid (98.7)	Labrid (100.0)	---	Labrid (96.9)	Labrid (95.7)
	1975	Scomber(32.4)	Labrid (51.4)	Anchoa (31.5)	Anchoa (45.0)	Anchoa (55.5)	Anchoa (43.5)
		Labrid (32.2)	Scomber(29.2)	Scomber(27.4)	Labrid (30.3)	Labrid (25.6)	Scomber(39.4)
		Anchoa (32.1)		Labrid (23.3)			
EGGS	1976	Labrid (59.7)	Labrid (87.9)	Anchoa (55.7)	Labrid (46.8)	Anchoa (60.3)	Anchoa (53.2)
		Anchoa (20.8)		Labrid (44.2)	Anchoa (35.1)	Labrid (32.3)	Labrid (34.9)
EGGS	1977	Anchoa (86.8)	Anchoa (93.6)	Anchoa (93.9)	Anchoa (93.4)	Anchoa (93.0)	Anchoa (77.2)
LARVAE							
LARVAE	1974	Anchoa (99.3)	Anchoa (99.4)	Anchoa (100.0)	---	Anchoa (98.6)	Anchoa (99.3)
	1975	Anchoa (98.1)	Anchoa (95.8)	Anchoa (90.2)	Anchoa (98.4)	Anchoa (94.3)	Anchoa (90.2)
	1976	Anchoa (74.0)	Anchoa (91.2)	Anchoa (71.1)	Anchoa (91.2)	Anchoa (72.3)	Anchoa (92.3)
	1977	Anchoa (97.9)	Anchoa (87.6)	Anchoa (89.4)	Anchoa (91.3)	Anchoa (80.7)	Anchoa (99.9)

() = Percent Composition

--- = No Sample

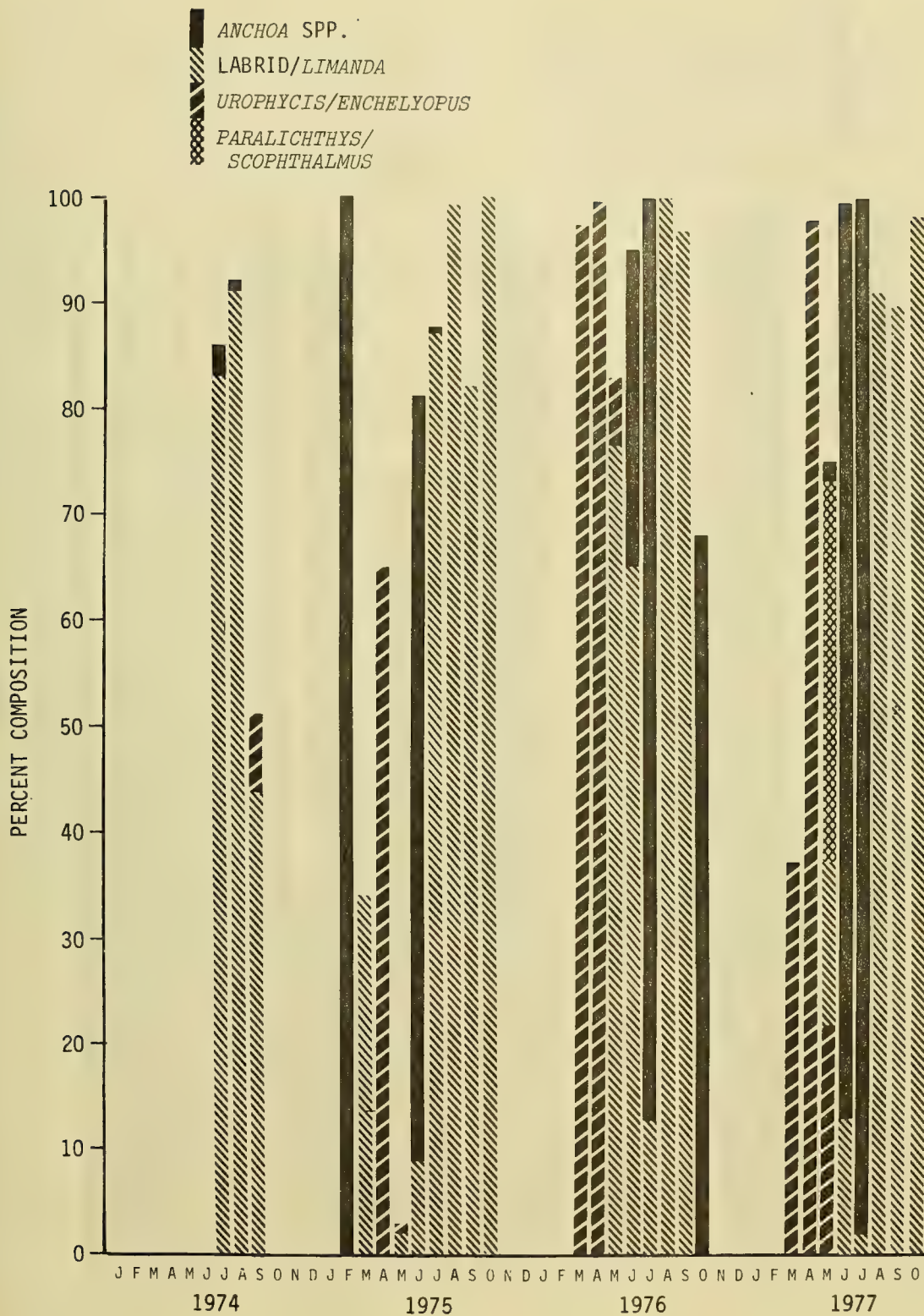


Figure 4-23. Overall percent composition of fish eggs of selected species in New Haven Harbor during each sampling period from 1974 through 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

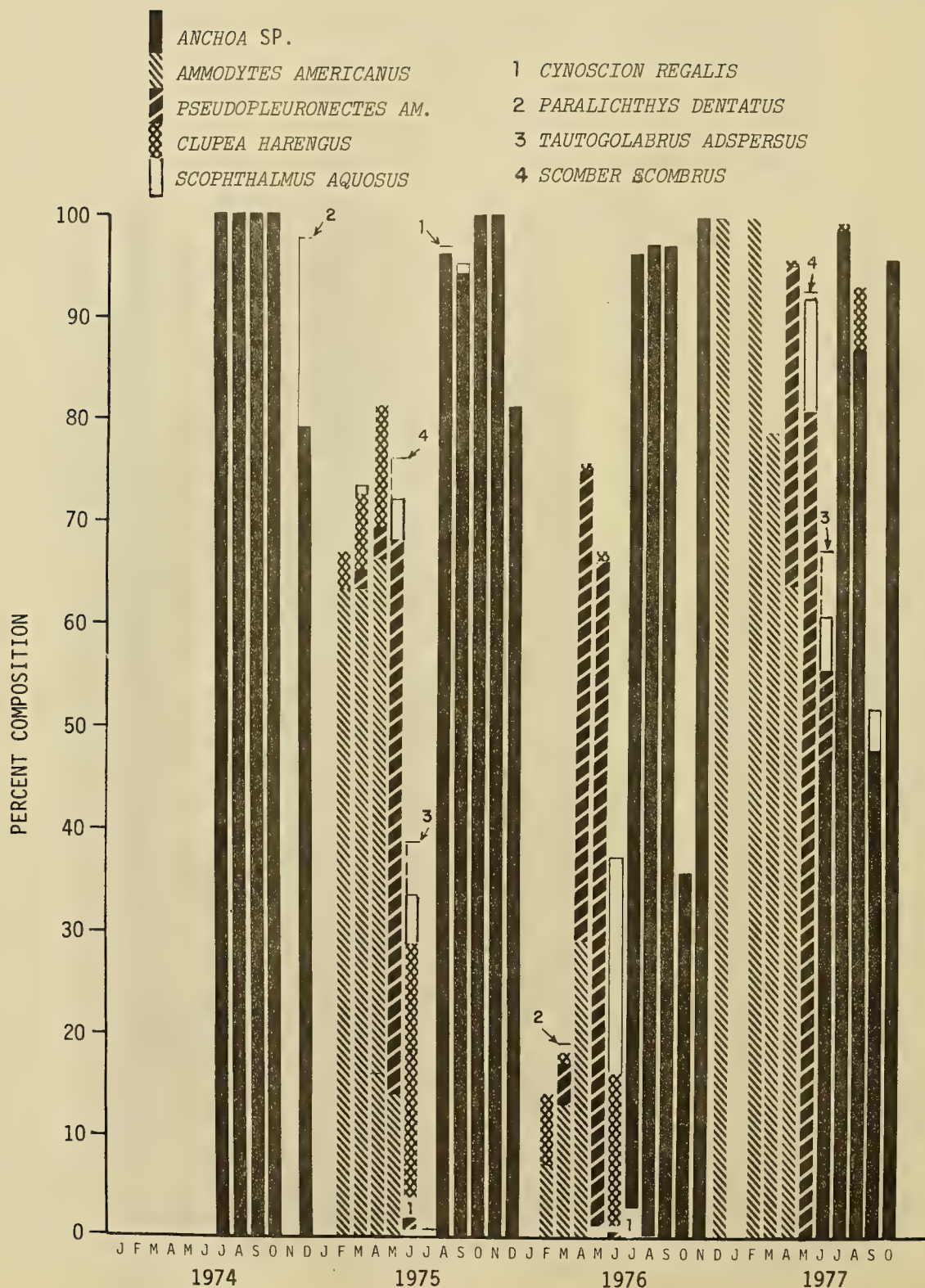


Figure 4-24. Overall percent composition of fish larvae of selected species in New Haven Harbor during each sampling period from 1974 through 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

to *Anchoa* spp., *Ammodytes americanus* (February-April) and *Pseudopleuronectes americanus* (April-May) larvae were seasonal dominants (Figure 4-24). Fish larval densities were most often highest at Station 20, and to a lesser extent, Stations 11 and 3, and least abundant at Station 6 (Table 4-9). *Anchoa* spp. larvae accounted for 71 to 100% of the larvae collected at a given station during any sampling year (Table 4-10). Larval abundance changed little between pre- and post-operational sampling dates (Table 4-9).

General seasonal comparisons of total egg and larval abundance may be made between recent data from New Haven Harbor and that presented by Richards (1959) for Station 1 near Milford, Connecticut for the years 1952 through 1955. Differences in sampling gear (Richards used a 12.5-cm Clarke-Bumpus sampler with 570 μ m and 366 μ m mesh nets) and station location limit the conclusions, but comparison of general abundance levels is instructive. As shown in Table 4-11, seasonality was quite similar and abundances were generally within an order of magnitude; dominant taxa were also similar (Tables 4-6, 4-7 and 4-8). On the other hand, comparison with Millstone Point data (Battelle, 1977) showed that egg and larval densities in New Haven Harbor (daytime collections) were up to several orders of magnitude less than at Millstone where nighttime oblique hauls with 333 μ m mesh nets (61 cm diameter) were made. Such differences probably reflect day-night differences due to avoidance and vertical migration (Clutter and Anraku, 1968) more than differences in gear type.

Selected Species

Anchoa sp.

Anchoa mitchilli eggs have been present in Long Island Sound from June through August at water temperatures ranging between 13.3-24.4C and salinities of 19.3-27.9 ppt (Herman, 1963; Wheatland, 1956). Both eggs and larvae are more abundant inshore (<20m) (Herman, 1963; Richards, 1959; Wheatland, 1956), with eggs more abundant at the surface

TABLE 4-11. COMPARISON OF ICHTHYOPLANKTON ABUNDANCE ($\#/m^3$) AT RICHARDS' (1959) STATION 1, 1952 THROUGH 1955 TO THE AVERAGE¹ OF NEW HAVEN HARBOR STATIONS FROM 1974 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	WINTER (DEC-FEB)	SPRING (MAR-MAY)	SUMMER (JUN-AUG)	FALL (SEP-NOV)
FISH EGGS STATION 1				
1952	---	1.45	47.36	0.59
1953	0.00	1.01	3.66	0.00
1954	0.00	1.38	18.25	0.00
1955	0.00	1.67	48.50	0.03
NEW HAVEN HARBOR				
1974	---	---	1.61	<0.01
1975	<0.01	6.89	9.04	<0.01
1976	0.00	3.47	13.52	0.03
1977	<0.01	2.52	51.02	0.02
FISH LARVAE STATION 1				
1952	---	0.23	1.45	2.46
1953	0.07	0.06	0.20	0.48
1954	0.24	0.04	1.32	0.24
1955	0.19	0.17	3.06	0.14
NEW HAVEN HARBOR				
1974	---	---	2.53	0.01
1975	0.04	0.12	4.46	0.02
1976	0.01	0.26	2.87	0.04
1977	0.01	0.42	8.20	0.02

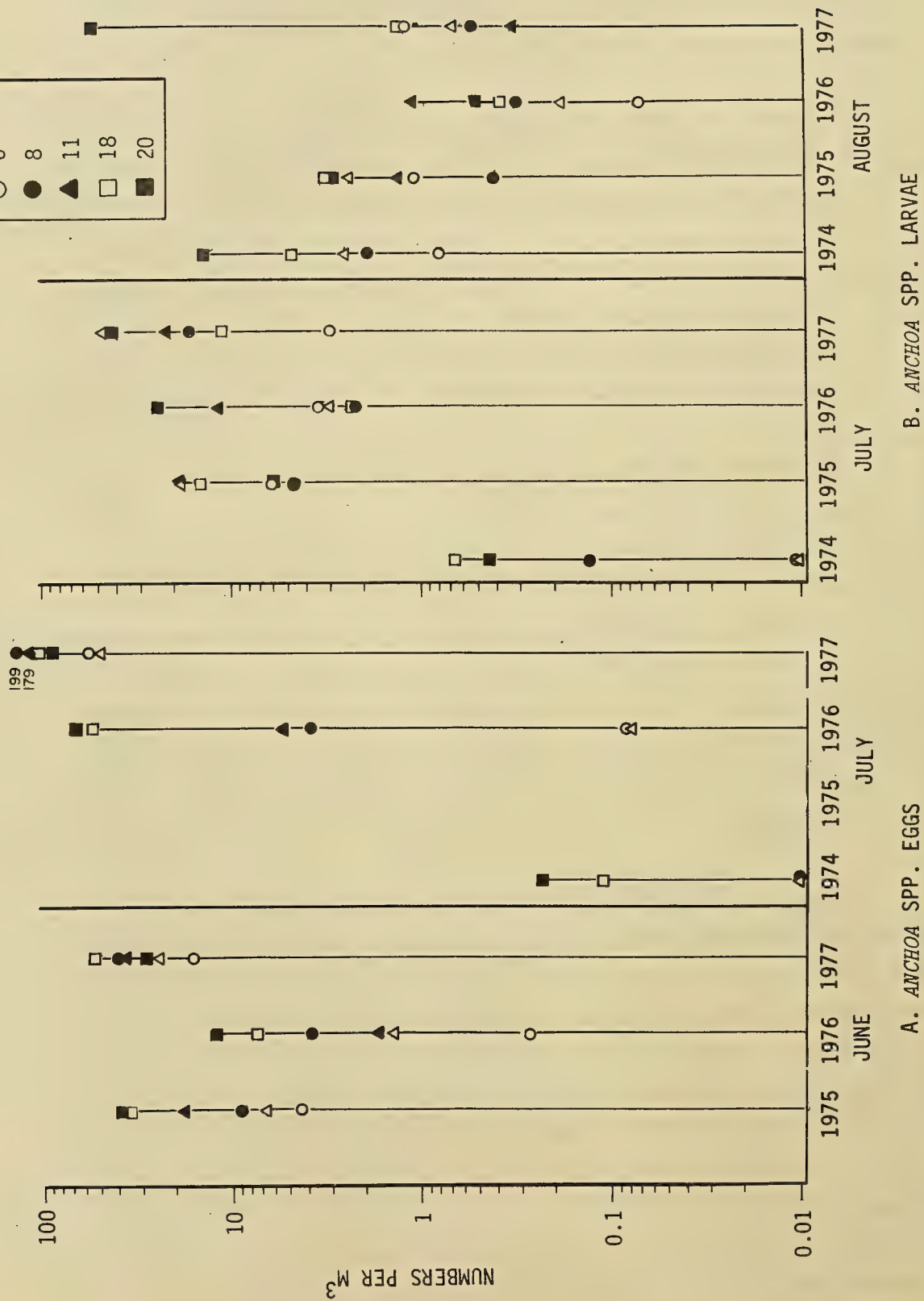
¹ Mean of all stations and tides

--- = No sample

(Williams, 1968) and larvae more abundant near the bottom (Pearcy and Richards, 1962). No ecological information is available on spawning of *A. hepsetus* in the Long Island Sound area.

Anchoa spp. eggs (Figure 4-25) were generally present in New Haven Harbor from May through August with a June/July peak. During 1975 and 1976 most were collected at Stations 18 and 20, while in 1977 more were collected at Stations 8, 11, 18 and 20; lowest densities were generally found at Station 6. During 1974, *Anchoa* spp. egg density was too low to describe a spatial pattern. Mean abundance over equivalent time periods (May through October) increased each year with the 1977 mean approximately seven times that of the 1975 mean. Richards (1959) also reported marked fluctuations (2100% increase) in *A. mitchilli* eggs at her Long Island Sound Station 1 between 1952 and 1953. This increase was postulated to be related to food supply (i.e., suitable zooplankton); no such relationship was evident with New Haven Harbor zooplankton. Mean egg densities during 1952 and 1953 (Wheatland, 1956) were similar (11.04 and 1.48/m³, respectively) to densities observed in New Haven Harbor from 1974 through 1977, although August densities in 1952 and 1953 were markedly higher than August densities observed in New Haven Harbor from 1974 through 1977. During June and July from 1974 through 1977, variation in abundance between years for each station in New Haven Harbor was generally similar (Figure 4-25).

Anchoa spp. larvae (Figure 4-25) were generally present from June through September with maximum abundance occurring during either July (1975 through 1977) or August (1974). Distribution within the harbor did not indicate a marked affinity for any particular station; lowest numbers, however, usually occurred at Stations 6 and 8. Annual mean abundance was generally similar from 1974 through 1976, with an increase noted during 1977. Wheatland's (1956) mean densities of *A. mitchilli* larvae in Long Island Sound for June through December in 1952 and 1953 (0.84 and 0.24/m³, respectively) were somewhat less than the densities observed in New Haven Harbor during this study. Such differences may of course reflect differences in sampling gear as noted



above, but may also be due to the preference for inshore areas by anchovies (Wheatland, 1956; Herman, 1963).

May through December larvae:egg ratios for 1975 through 1977 (1:1.56, 1:3.87 and 1:5.31, respectively) are comparable with the 1:5.5 ratio calculated by Wheatland (1956) for 1953; the 1952 ratio (1:14.4) may have reflected sampling errors as well as increased mortality (Wheatland, 1956). Thus, it appears that egg mortality estimates from New Haven Harbor are fairly consistent with data from two decades earlier.

Pseudopleuronectes americanus

Winter flounder, *Pseudopleuronectes americanus*, spawn in upper reaches of estuaries at salinities from 3.2 to 29.5 ppt. Eggs and early larval stages are nondispersive, remaining near the areas in which they were spawned. In the Long Island Sound area, spawning commences in December, peaks in March and then declines (Wheatland, 1956; Percy, 1962; Herman, 1963). In New Haven Harbor, *P. americanus* larvae were present from March through June in 1975 and 1976 and from April through July in 1977 (Figure 4-26). Peak densities occurred during May (1975) and April (1976 and 1977); the 1974 program did not cover the appropriate time period to contribute information about *P. americanus* larval distribution (Table 4-12). April and/or May maxima have also been observed in Long Island Sound by Battelle (1977) and Wheatland (1956) (Table 4-12), while Percy (1962) found maximum larval densities during March and April 1959 in the Mystic River. Such differences in timing of maximum densities reflect tidal action removing larvae from the estuaries (Wheatland, 1956). Warfel and Merriman (1944) believed that the Morris Cove area of New Haven Harbor (sampled with 30-foot seine) was an important nursery area.

Monthly concentrations of winter flounder larvae in New Haven Harbor from 1974 through 1977 were generally lower than those found by Percy (1962) in the Mystic River, as well as by Battelle (1977) near Millstone Point in 1976 and in Long Island Sound in 1954 and 1955 were

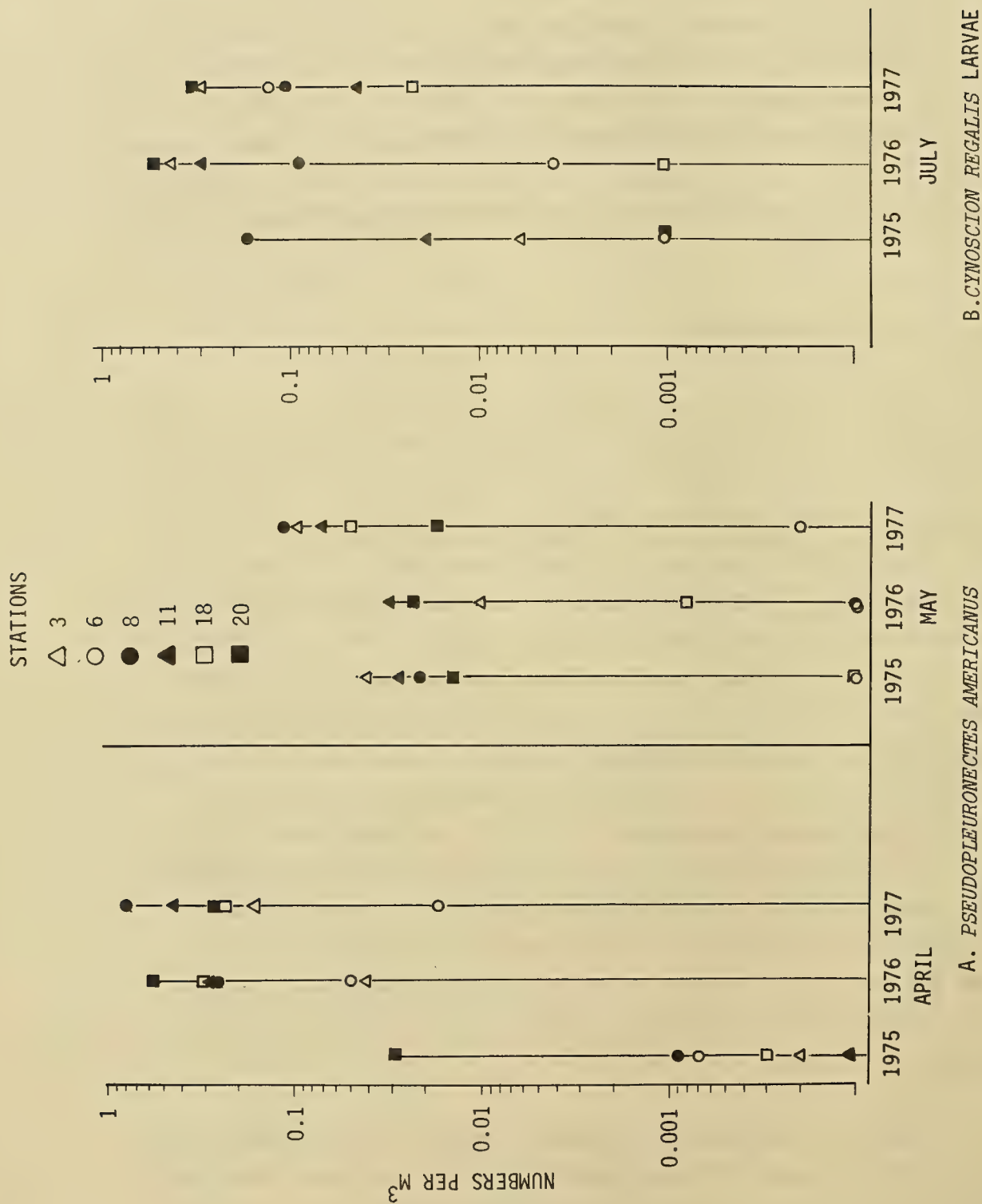


Figure 4-26. Abundance by station of *Pseudopleuronectes americanus* larvae (during April and May 1975 through 1977) and *Cynoscion regalis* larvae (during July 1974 through 1977). New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 4-12. ABUNDANCE ($\#/m^3$) OF WINTER FLOUNDER (*PSEUDOPLEURONCTES AMERICANUS*) LARVAE IN NEW HAVEN HARBOR AND ADJACENT WATERS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

MONTHLY MEANS (EXCLUDING STATION 11) STATION MEANS

NEW HAVEN HARBOR

YEAR	MAR	APR	MAY	JUN	JUL	3	6	8	11	18	20
1974	---	---	---	---	0.000	0.000	0.000	0.000		0.000	0.000
1975	0.001	0.010	0.015	0.001	0.000	0.009	0.002	0.006	0.010	0.001	0.009
1976	0.012	0.238	0.009	<0.001	0.000	0.022	0.010	0.051	0.063	0.059	0.117
1977	0.000	0.293	0.054	0.023	0.001	0.072	0.005	0.179	0.105	0.056	0.059

MILLSTONE POINT, CONNECTICUT¹

1976	0.076	0.348	0.079	0.001	0.000
------	-------	-------	-------	-------	-------

LONG ISLAND SOUND²

1952	0.000	0.04	0.10	0.01	0.000
1953	0.02	0.07	0.03	0.00	0.000

¹ From Table F-7, Battelle (1977)

² From Wheatland (1956)

--- = No sample

generally greater than those in Long Island Sound during 1952 and 1953 (Table 4-12). It must be reiterated that such comparisons are limited by differences in gear, gear deployment, and study design, which may either mask or exaggerate naturally-occurring differences such as those due to differences in year-class strength. Generally, however, for the years compared, densities of *P. americanus* larvae in New Haven Harbor were lower than those found in the Mystic River and near Millstone Point (night collections) and those in Long Island Sound. Mean abundances were generally greatest at Stations 8, 20 and 11 and lowest at Station 6; similar densities were observed during 1976 and 1977 (Table 4-12). Mean abundance at Station 8 (March through July) underwent the greatest increase between 1975 and 1976 (850%) and 1976-1977 (350%).

Cynoscion regalis

Weakfish, *Cynoscion regalis*, are summer migrants in the Long Island Sound area (Bigelow and Schroeder, 1953). Although several studies have described spawning activities north of Chesapeake Bay (cf. Merriner, 1976), Harmic (1958, cited in Merriner, 1976) hypothesized that northern spawning is probably not sufficient to maintain northern populations, with recruitment to these areas dependent upon fish (age III+) spawned in more southern waters.

Weakfish larvae are present in Long Island Sound waters between June and September (Merriman and Sclar, 1952; Wheatland, 1956; Richards, 1959; Herman, 1963; Battelle, 1977) and have been most abundant during July (Table 4-13). Larval densities in New Haven Harbor during July have generally been one to two orders of magnitude greater than those reported from Millstone Point in 1976 (Battelle, 1977) and an order of magnitude greater than those from Long Island Sound proper in 1952 and 1953 (Wheatland, 1956) (Table 4-13). Within New Haven Harbor, fewest larvae have been collected at Stations 6 and 18, while greatest concentrations have occurred at the two stations furthest apart, Stations 3 and 20; no explanation is available for this pattern (Figure 4-26).

TABLE 4-13. ABUNDANCE ($\#/m^3$) OF WEAKFISH (*CYNOSCION REGALIS*) LARVAE IN NEW HAVEN HARBOR AND ADJACENT WATERS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

MONTHLY MEANS
(EXCLUDING STATION 11)

STATION MEANS

NEW HAVEN HARBOR

	JUN	JUL	AUG	3	6	8	11	18	20
1974	---	0	0	0	0	0	---	0	0
1975	.004	.034	.007	.003	0	.055	.007	.011	.007
1976	.001	.208	0	.142	.001	.030	.099	<.001	.113
1977	<.001	.175	0	.100	.042	.036	.015	.007	.107

MILLSTONE POINT, CONNECTICUT¹

1976	.002	.005	0
------	------	------	---

LONG ISLAND SOUND²

1952	0	.08	0
1953	0	.05	0

¹ From Table F-7, Battelle (1970)

² From Wheatland (1956)

--- = No sample

Inter-year differences in abundance have been noted. While no weakfish larvae were collected during 1974 and only low numbers during 1975, levels during 1976 and 1977 were similar to each other and markedly greater than 1975 (Table 4-13). *C. regalis* has a history of variable spawning success (Austin, 1976) indicating that such fluctuations may be intrinsic to the biology of the species. No consistent pattern of inter-year variation by station was observed, although abundance at Stations 3, 11 and 20 increased through 1976 and then decreased during 1977 (Figure 4-26).

Labrid eggs

Labrid eggs were present in New Haven Harbor ichthyoplankton collections from May through September from 1975 through 1977, with low densities also reported during March 1975 and in October of 1975 and 1977. Peak abundance of Labrid eggs occurred during June and July both in New Haven Harbor and in other areas of Long Island Sound (Table 4-14). This temporal distribution was similar to Herman's (1963) and Richards' (1959) data for cunner (*Tautogolabrus adspersus*) in Long Island Sound. Battelle (1977) reported Labrid/*Limanda* eggs in the Millstone Point area between January and November. Since spawning of yellowtail flounder (*Limanda ferruginea*) commences in March (Smith et al., 1978), there is a possibility that some of the eggs collected near Millstone Point were *L. ferruginea*.

More Labrid eggs were collected at Station 20 during 1974, 1976 and 1977 although similar mean concentrations occurred at Stations 11, 20 and 8 during 1975; Station 6 generally had the fewest eggs (Table 4-14). Mean egg-density was relatively low during 1975, increased approximately by a factor of five in 1976 and then decreased by about one-half (50%) in 1977. These trends were generally consistent at all stations, with a marked increase noted at four stations between 1975 and 1976 and a decrease at three stations between 1976 and 1977 (Figure 4-27).

TABLE 4-14. ABUNDANCE ($\#/m^3$) OF LABRID EGGS IN NEW HAVEN HARBOR AND ADJACENT WATERS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

NEW HAVEN HARBOR

MONTHLY MEANS (EXCLUDING STA. 11)

STATION MEANS

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	3	6	8	11	18	20
1974	---	---	---	---	2.152	.609	.001	0	.330	.031	1.016	---	.748	1.327
1975	.007	0	.579	1.744	.144	1.213	.007	<.001	.480	.228	.567	.610	.433	.599
1976	0	0	3.052	8.218	3.427	4.080	.089	0	.532	.604	3.090	1.150	1.798	6.166
1977	0	0	1.048	5.011	1.834	.604	.028	.003	.392	.315	1.012	.645	.716	2.895

MILLSTONE POINT, CONNECTICUT¹

YEAR	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1973	0	0	48.244	2061.5	658.554	64.137	1.706	.027
1974	.471	1.730	197.626	413.303	700.484	9.077	.331	.004

LONG ISLAND SOUND²

YEAR	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1952	0	0	1.2	3.14	1.38	.16	.09	.05
1953	0	0	1.38	7.97	1.78	2.11	0	0

¹ From Table F-7, Battelle (1977); includes Labridae and Labrid/Limanda types

² From Wheatland (1956)

--- = No sample

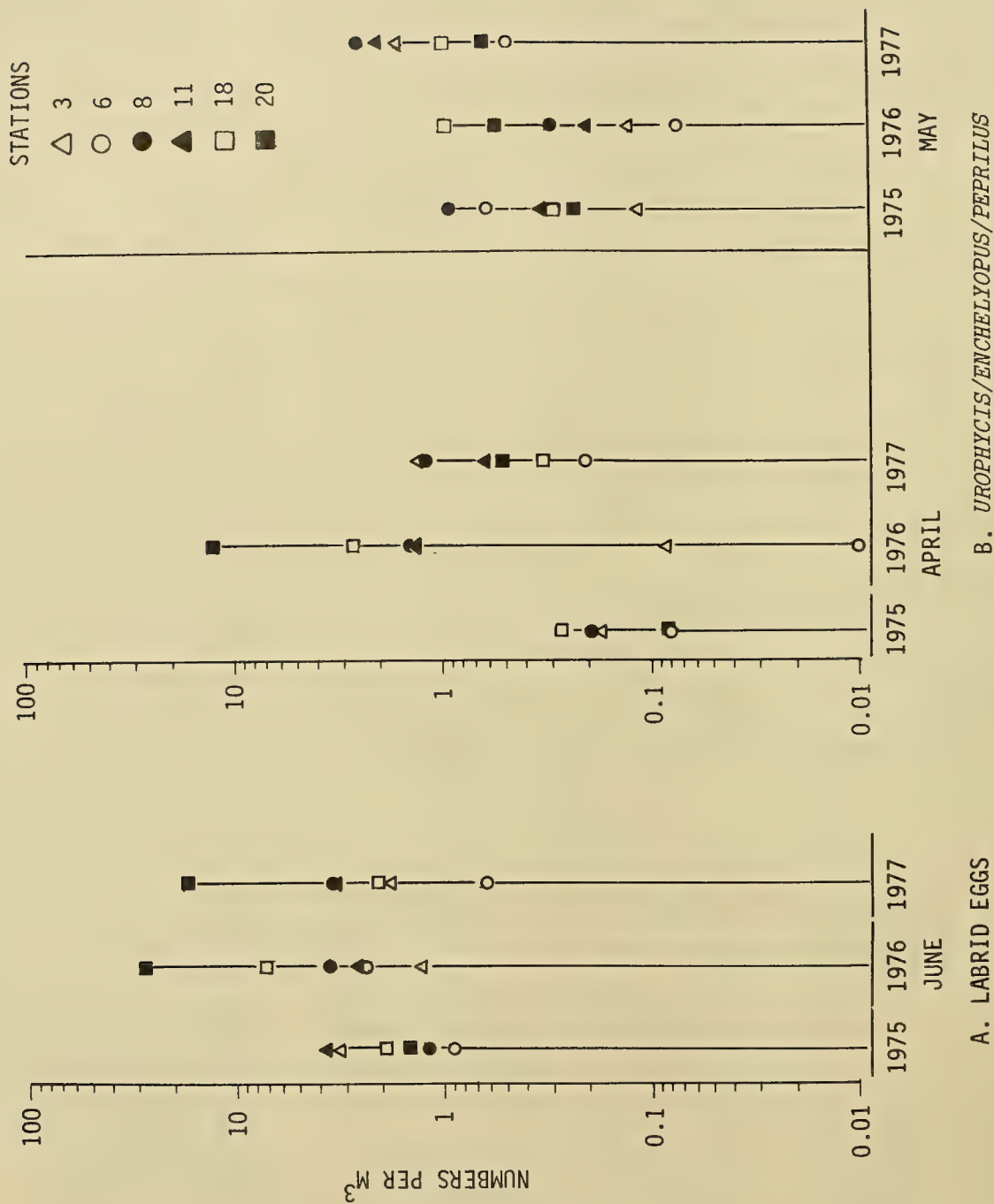


Figure 4-27. Abundance by station of Labrid eggs (during June), *Urophycis/Enchelyopus/Peprilus* eggs (during April and May). New Haven Harbor Ecological Studies Summary Report, 1979.

Labrid egg abundance in New Haven Harbor compared favorably with Herman's (1963) data from Narragansett Bay and with Wheatland's (1956) data from Long Island Sound (Table 4-14). However, abundances at Millstone Point during 1973 and 1974 (Battelle, 1977) were generally two orders of magnitude greater than those reported from other areas (Table 4-14). These comparisons suggest that New Haven Harbor is not a unique spawning area for Labrids.

Urophycis/Enchelyopus/Peprilus Eggs

As noted earlier, this group probably receives its greatest contribution from *E. cimbrius*, since this species has been the most abundant of this egg type in other investigations (Wheatland, 1956; Richards, 1959; Herman, 1963; Williams, 1968; Battelle, 1977). Eggs of this type were present in New Haven Harbor between February and September, corresponding to the observations of Battelle (1977) and Wheatland (1956). Eggs were most abundant during April and May both in New Haven Harbor as well as other areas of Long Island Sound (Table 4-15).

Greater numbers of eggs were collected at Station 8 in 1975 and 1977, while during 1976 they were most abundant at Station 20; lowest abundance in each year occurred at Station 6 (Table 4-15). Inter-year differences were evident, with 1976 a peak year. This differed from the pattern at Millstone Point where 1975 was a peak year and 1976 was a relatively poor year (Table 4-15). Egg densities in New Haven Harbor from 1975 through 1977 were generally similar to both Millstone (1973, 1974, and 1976) and Long Island Sound (1952 and 1953) (Table 4-15). Inter-year variation by station was somewhat variable and may reflect differences in spawning success of the component species (Figure 4-27).

In summary, the ichthyoplankton assemblage in New Haven Harbor was dominated by *Anchoa* spp. eggs and larvae, Labrid eggs and *Urophycis/Enchelyopus/Peprilus* eggs, and was similar to assemblages noted in other

TABLE 4-15. ABUNDANCE ($\#/m^3$) OF *UROPHYCIS/ENCHELYOPUS/PEPRILUS* EGGS IN NEW HAVEN HARBOR AND ADJACENT WATERS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

NEW HAVEN HARBOR

MONTHLY MEANS (EXCLUDING STA 11)

STATION MEANS

	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	3	6	8	11	18	20
1974	---	---	---	---	---	0	0	0	0	0	0	0	---	0	0
1975	.004	.001	.160	.428	.159	<.001	<.001	0	0	.043	.018	.137	.068	.090	.120
1976	0	.641	3.340	.404	.010	.030	.007	.001	0	.108	.025	.360	.351	.536	1.742
1977	0	.013	.717	1.239	.003	.002	.002	.001	0	.370	.087	.467	.333	.166	.146

MILLSTONE POINT, CONNECTICUT¹

YEAR	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1973	0	0	0	.540	.690	.783	.163	.419	.003
1974	0	.152	1.302	.745	2.569	1.852	.579	.016	.054
1975	.046	.755	5.593	4.032	1.388	3.682	.267	.019	0
1976	0	0	.038	.138	.440	.072	.007	0	0

LONG ISLAND SOUND²

YEAR	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1952	---	.44	.96	1.48	.19	0	0	0	0
1953	0	.41	.94	.29	.07	0	C	0	0
1954	.04	.11	---	---	---	---	---	---	---

¹From Table F-7, Battelle (1977); includes Labridae and Labrid/Limanda types.

²From Wheatland (1956)

--- = No sample

inshore areas of Long Island Sound over a 30-year period. Fish-egg densities were generally low except during June and July when *Anchoa* spp. and Labrids predominated. *Urophycis/Enchelyopus/Peprilus* eggs were most abundant during April and May. Total fish eggs and *Anchoa* spp. eggs were most abundant at Stations 18 and 20 (1975, 1976) and 8, 11, and 18 (1977). Labrid eggs were generally most abundant at Station 20. *Urophycis/Enchelyopus/Peprilus* eggs were most abundant at Stations 8 (1975, 1977) and 20 (1976). Fish larvae were most abundant during July and August, reflecting the appearance of *Anchoa* spp. larvae. Larvae of *Cynoscion regalis*, an important sportfish, were also most abundant during July, while larvae of *Pseudopleuronectes americanus*, a major commercial and recreational fish, were most abundant during April and May. Total fish larvae were most abundant at Stations 20, 11 and 3. *Anchoa* sp(p). larvae showed little evidence of spatial heterogeneity throughout the survey period. *C. regalis* larvae did show evidence of spatial heterogeneity but the pattern was difficult to interpret. *P. americanus* larvae were most abundant at Stations 8, 20 and 11 with Station 8, located in proximity to the New Haven Harbor Station, undergoing the greatest relative increases in annual abundance between 1975 and 1977.

ANALYSIS OF IMPACTS

There are two principal means by which the plankton community may be directly impacted by the operation of New Haven Harbor Station: 1) by being drawn through the power plant's cooling system, (entrainment). and 2) by being exposed to the heated discharge as it diffuses and mixes with the receiving water. In the case of power-plant passage, both temperature and mechanical injury appear to be instrumental in causing mortality; temperature alone is responsible for the detrimental effects of plume entrainment. Other potential causes of death include stresses associated with abrupt increases and decreases in hydraulic pressure (e.g., formation of gas emboli in body fluids) as organisms pass through various parts of the cooling system, and contact with biocides and other

chemicals released with the cooling water (Clark and Brownell, 1973; Marcy, 1975; EPA, 1977a). New Haven Harbor Station does not utilize biocides in its cooling water system.

Of the two potential sources of impact, power plant passage has been considered to pose the more serious problem (Miller and Beck, 1975). Zooplankton (including ichthyoplankton) mortalities due to plant passage range from 0 to 100% (Marcy, 1975; Jeffries and Johnson, 1976; Cannon *et al.*, 1978). Recent studies have indicated that entrainment mortalities were low at temperatures below thermal tolerance limits for species tested and increased as lethal thermal thresholds (generally 30°C) were approached and exceeded (Cannon *et al.*, 1978). Though it probably reflects a substantial overestimate of the loss due to entrainment (cropping), assumption of 100% entrainment mortality certainly presents the worst-possible situation regarding entrainment effects. If entrainment loss projections based on 100% mortality are within an acceptable level, then further effort to define precise mortality in a given system is unnecessary. Furthermore, survivors of plant-passage stresses may be more susceptible to infection, predation, and developmental aberrations than organisms not subjected to passage through the cooling system (Clark and Brownell, 1973; Ulanowicz, 1975).

It is difficult to directly address the question of how well natural populations can accomodate attrition rates associated with power-plant passage. Enright (1977), for example, has pointed out that obtaining estimates of the quantities of meroplankters passing through a power-plant cooling system has little practical value since the relationship between such quantities (assumed to represent total losses) and post-larval recruitment is rather obscure. To evaluate power-plant impact on attached or infaunal organisms, Enright (1977) recommends investigation of changes in rates of post-larval settlement on artificially prepared substrates. This general approach was utilized in the exposure panel studies presented in Section 5 of this report. Further guidance with regard to this question has been provided by the US EPA (1977b). Specifically, EPA (1977b) states:

Any significant change in standing crop may indicate an adverse impact resulting from the heated discharge, and any appreciative alteration in the composition and relative abundance...constitutes an imbalance in the community and indicates possible adverse impact.

Although phytoplankters are susceptible to the same thermal and mechanical stresses as zooplankters, the former possess enormously greater reproductive potential (often doubling population size in less than a day) and thus can more easily accommodate extremely high individual cell attrition rates, which are also caused naturally by the cells sinking and by grazing pressures. Thus, there is no reason to consider individual phytoplankton cell deaths a significant issue with regard to power plant impact. What should be considered, however, is the potential for changes in overall levels of production and standing stock and/or a shift in the kinds of phytoplankton produced in the altered system (Yentsch, 1977).

Most of the studies designed to examine effects of power-plant passage on phytoplankton populations have focused on short-term alterations. In general, these studies have illustrated that, in temperate latitudes, production is stimulated during cooler months and inhibited during warmer months (Warriner and Brehmer, 1966; Morgan and Stross, 1969) and that biocide addition (not utilized at New Haven Harbor Station) may be more important than heat in reducing production levels (Flemer and Sherk, 1977). Due to natural variability in phytoplankton standing stock and its dependence on many factors, it becomes difficult to isolate causes of long-term changes in production levels; such assessment is particularly difficult in nutrient-enriched areas (such as New Haven Harbor) where standing stock varies considerably among years (Flemer and Sherk, 1977). With respect to changes in the kinds of phytoplankton produced, Carpenter (1973) has demonstrated experimentally that heat addition can accelerate natural succession from diatoms to dinoflagellates; however, in natural systems, the dynamics of toxic dinoflagellate blooms remain poorly understood. Hanson and Gilfillan (1975), however, have implicated two major aggravators of red-tide conditions: sewage discharge and dredging.

As evidenced by chlorophyll *a* values (Figure 4-3), phytoplankton blooms have progressively increased in magnitude during the post-operational years (1975 through 1977). Accompanying such changes has been an increase in the intensity of late-winter/early spring blooms of *Skeletonema costatum*. Non-toxic dinoflagellate blooms have occurred during both preoperational (e.g., June 1974) and post-operational (e.g., June 1976) periods; in addition, Conover (1956) alluded to red-tide conditions in New Haven Harbor during the early 1950's. There has been no evidence of causal relationships between Harbor Station operations and changes in phytoplankton population parameters.

A comparison of monthly mean densities (stations, depths and tides averaged) for July 1973-October 1977 is presented for pre- versus post-operational comparisons of nine selected zooplankton taxa in Figures 4-28 to 4-30^{*}. Table 4-16 summarizes the differences observed in zooplankton assemblages by evaluating whether or not operational data (as converted to CB equivalences) fell within the ranges established by preoperational monitoring. For most taxa, operational estimates fell within or exceeded these ranges during at least 10 months (Table 4-16). The general category of copepod copepodites were consistently less abundant in the operational period, probably due to the fact that many were classified as *Acartia* copepodites during this period (Figures 4-28, 4-29 and 4-30). All other species showing reduced abundance since operation commenced did so in months of peak abundances. Our conclusion regarding the CB data was that this method overestimated density during peak abundance periods. This interpretation of the comparability study results (Appendix 4-1) implies that high estimates of preoperational zooplankton densities were erroneous, that post-operational data are accurate, and that there is no evidence to indicate any adverse impact of Harbor Station activities on zooplankton populations. Operational

* Data from samples taken by the 1/2 m net were adjusted to CB equivalences by application of the regression equations defined in the comparability study. While these equations did not describe the data well, they provide the best available method to approximate comparability between methods.



Figure 4-28. Mean density of selected species at all stations, depths and tides by month, July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

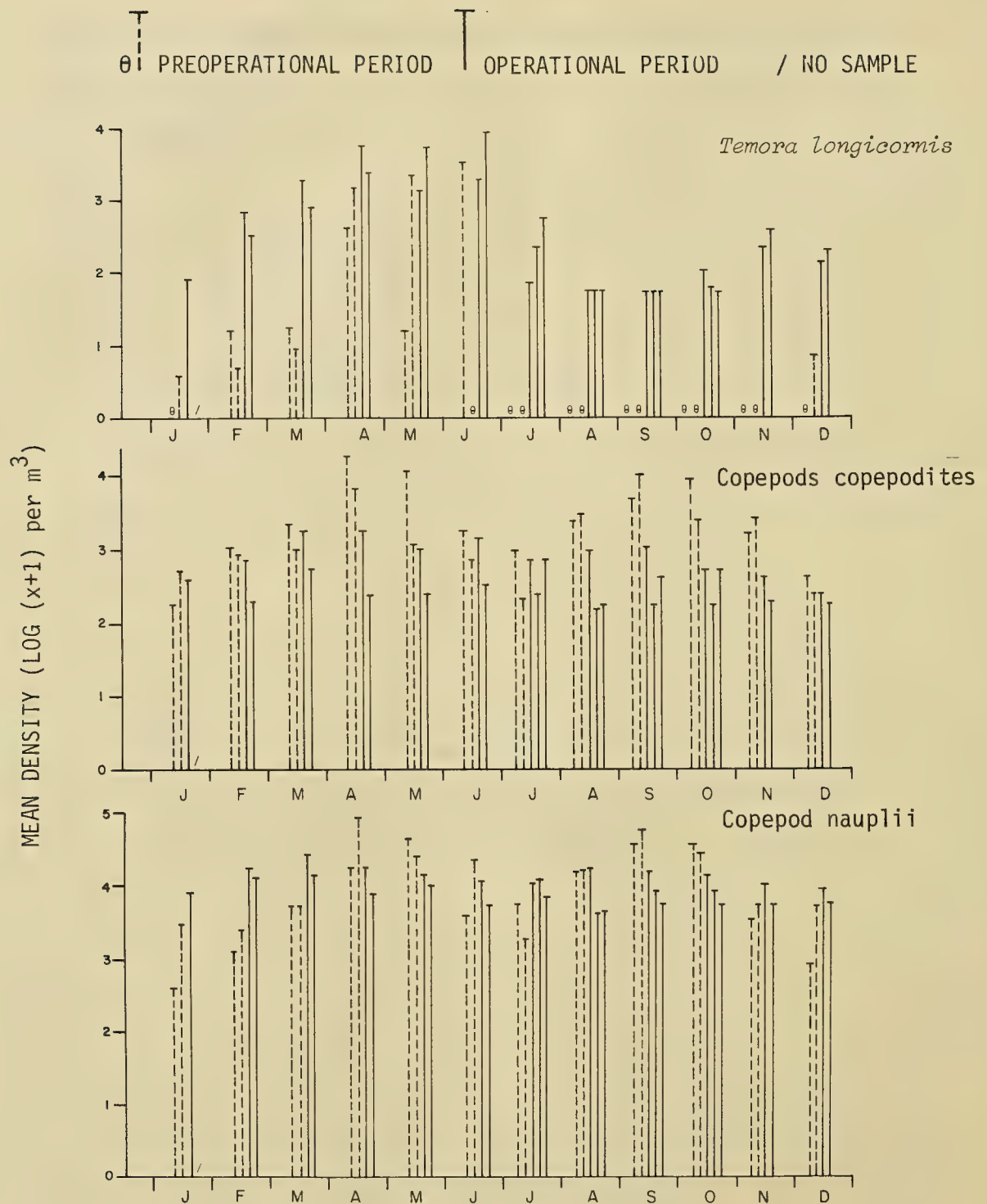


Figure 4-29. Mean density of selected species at all stations, depths and tides by month, July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

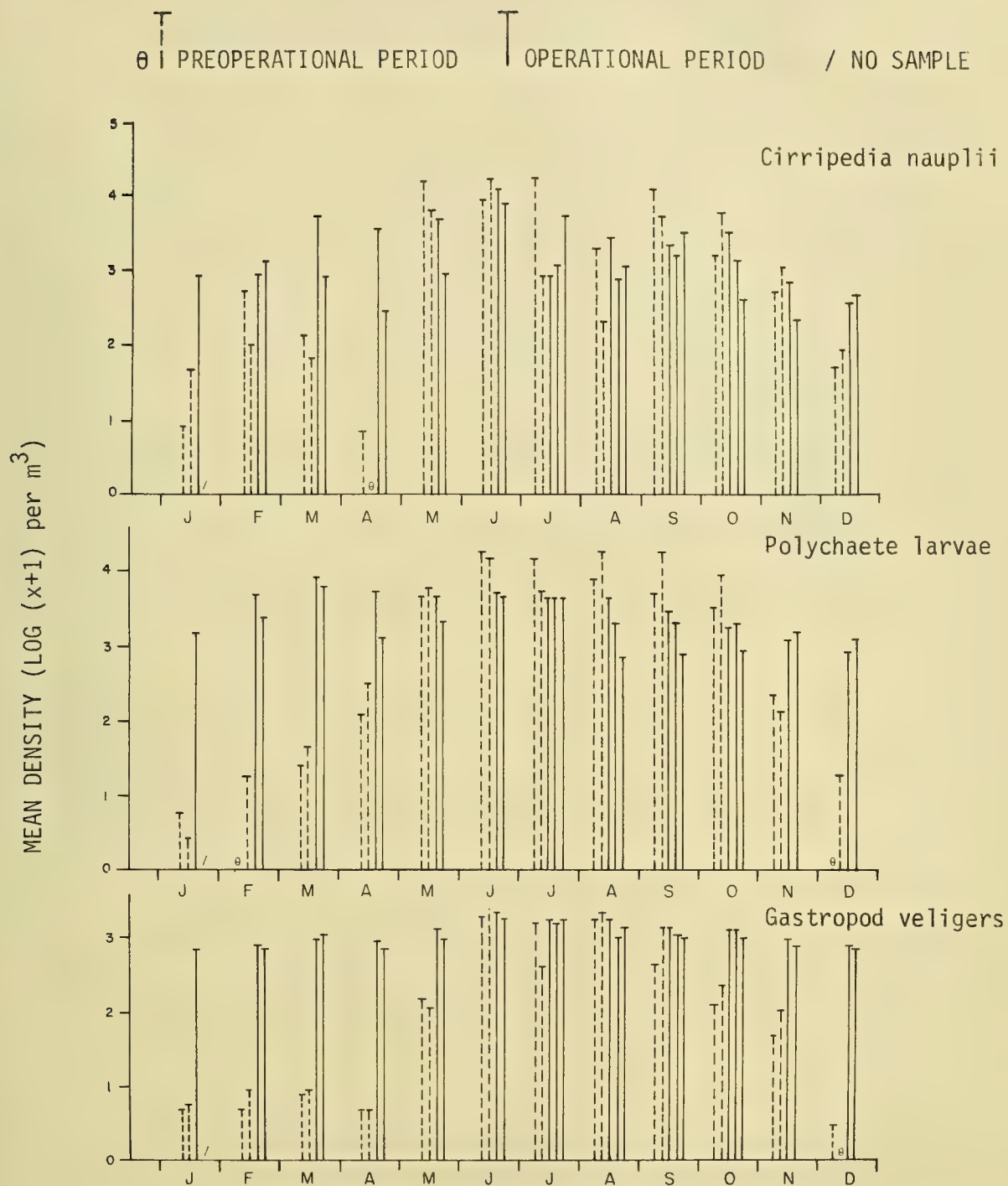


Figure 4-30. Mean density of selected species at all stations, depths and tides by month, July 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 4-16. RELATIVE DENSITIES OF SELECTED TAXA COMPARED BY MONTH BETWEEN OPERATIONAL AND PREOPERATIONAL YEARS. (OPERATIONAL DATA ADJUSTED FOR SAMPLING DIFFERENCES BY REGRESSION EQUATION)* NEW HAVEN HARBOR STATION ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	J	F	M	A	M	J	J	A	S	O	N	D
<i>Acartia coepodites</i>	+	+	+	+	0	0	+	+	+	+	+	+
<i>A. hudsonica</i>	0	0	0	-	-	0	+	+	0	+	+	+
<i>A. tonsa</i>	0	0	+	+	+	0	+	+	+	+	+	+
<i>Temora longicornis</i>	+	+	+	+	+	+	+	+	+	+	+	+
Copepod coepodites	0	-	0	-	-	0	0	-	-	-	-	-
Copepod nauplii	+	+	+	-	-	0	+	+	-	-	+	+
<i>Cirripedia</i> nauplii	+	+	+	+	-	0	0	+	-	0	0	+
Gastropod veligers	+	+	+	+	+	0	+	-	+	+	+	+
Polychaete larvae	+	+	+	+	0	-	-	-	-	-	+	+

- = Operational below preoperational range

+ = Operational above preoperational range

0 = Operational within preoperational range

* See discussion of zooplankton comparability - Appendix 4-1.

densities and species composition were consistent with those reported at Millstone Point (Battelle, 1977, 1978) and greater Long Island Sound (Deevey, 1952a, 1952b, 1956).

In New Haven Harbor, year-to-year fluctuations occurred in total ichthyoplankton abundance, as well as abundance of selected taxa, but were not indicative of impact, judging from the natural variability as seen in studies conducted in Long Island Sound and vicinity between 1943 and 1968. For some taxa (e.g., *Anchoa mitchilli*), numerical densities during periods of peak abundance increased, comparing the years 1974 and 1975 with 1976 and 1977. The number of taxa represented was lowest during the abbreviated 1974 program and was somewhat greater in years having expanded sampling programs. Dominant taxonomic groups were similar from year to year. Observed seasons of peak occurrence, dominant taxa, and species represented among the ichthyoplankton in New Haven Harbor all closely resembled comparable data collected and reported by previous investigators of Long Island Sound ichthyofauna.

Few spatial differences were detected in any of the plankton studies (NAI, 1978a; 1977a; 1976a; 1975a; 1974a; 1974b; 1973). All differences between stations were attributable to salinity, light and depth gradients and were independent of Harbor Station operations.

The overall conclusion is that plankton assemblages of New Haven Harbor which have existed subsequent to operation of New Haven Harbor Station are largely indistinguishable, qualitatively and quantitatively, from assemblages that existed prior to power plant operation. A notable exception to this generalization involves increases in phytoplankton standing crop. Though these increases may reasonably be attributable to influences such as improved water quality and expanded treatment of municipal waste discharges, monitoring data offers no means of evaluating this possibility.

4.0 LITERATURE CITED

- Austin, H. M. 1976. Distribution and abundance of ichthyoplankton in the New York Bight during the fall in 1971. N.Y. Fish Game J. 23(1):58-72.
- Battelle. 1977. Annual report on a monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Prepared for Northeast Utilities Service Company Report No. 14748.
- Bigelow, H. and W. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wild. Serv., Fish. Bull. 577 pp.
- Cannon, T. C., S. M. Jinks, L. R. King and G. J. Lauer. 1978. Survival of entrained ichthyoplankton and macroinvertebrates at Hudson River power plants. IN: L. D. Jensen (ed.). Fourth National Workshop on Entrainment and Impingement. EA Communications, Melville, N. Y. pp. 343-356.
- Caplan, R. I. 1977. Aquatic disposal field investigations, Eatons Neck Disposal Site, Long Island Sound. Appendix E. Predisposal baseline conditions of zooplankton assemblages. U.S. Army Engineer Waterways Experiment Station, Vicksburg and N. Y. Ocean Science Lab, Montauk. Tech. Rept. D-77-6. 104 pp.
- Carpenter, E. J. 1973. Brackish-water phytoplankton response to temperature elevation. Est. Coast. Mar. Sci. 1(1):37-44.
- Clark, J. and W. Brownell. 1973. Electric Power Plants in the Coastal Zone: Environmental Issues. Am. Litt. Soc. Spec. Publ. No. 7.
- Clutter, R. I. and M. Anraku. 1968. Avoidance of Samplers. IN: Zooplankton sampling. UNESCO.
- Crocker, R. 1965. Planktonic fish eggs and larvae of Sandy Hook estuary. Chesapeake Sci. 6(2):92-95.
- Deevey, G. B. 1952a. A survey of the zooplankton of Block Island Sound. Bull. Bing. Oceanogr. Coll. 13(3):65-119.
- _____. 1952b. Quantity and composition of the zooplankton of Block Island Sound, 1949. Bull. Bing. Oceanogr. Coll. 13(3):120-164.
- _____. 1956. Oceanography of Long Island Sound 1952-1954. V. Zooplankton: Bull. Bing. Oceanogr. Coll. 15:113-155.
- Enright. 1977. Power plants and plankton. Marine Pollution Bulletin, 8(7):158-163.
- EPA, 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. [C. I. Weber, ed.] Program Element 1BA027. Cincinnati.

- Flemer, D. and J. A. Sherk, Jr. 1977. The effects of steam electric station operation on entrained phytoplankton. *Hydrobiologia*. 55(1):33-44.
- Hanson, S. and E. Gilfillan. 1975. Effects of polluted and non-polluted sediments on the growth of *Gonyaulax tamarensis*. *Envir. Ltrs.* 9(1):33-41.
- Harmic, J. L. 1958. Some aspects of the development and ecology of the pelagic phase of the gray squeteague, *Cynoscion regalis* (Bloch and Schneider), in the Delaware estuary. Thesis, Univ. of Delaware, Newark. 84 pp.
- Herman, S. 1963. Planktonic fish eggs and larvae of Narragansett Bay. *Limnol. Oceanogr.* 8(1):103-109.
- Jeffries, H. P. and W. C. Johnson II. 1976. Petroleum, temperature, and toxicants: examples of suspected responses by plankton and benthos on the continental shelf. IN: B. Manowitz (ed.). Effects of energy-related activities on the Atlantic continental shelf. Conf. at Brookhaven Nat. Lab. Nov. 10-12, 1975. pp. 96-108.
- Leim, A. H. and W. B. Scott. 1966. Fishes of the Atlantic coast of Canada. *Fish Res. Bd. Can. Bull.* 155. 485 pp.
- Lillick, L. G. 1940. Phytoplankton and planktonic protozoa of the off-shore waters of the Gulf of Maine. Part II: Qualitative composition of the planktonic flora. *Trans. Am. Phil. Soc.* 31(3):193-237.
- Marcy, B. C., Jr. 1975. Entrainment of organisms at power plants, with emphasis on fishes -- an overview. pp. 89-106. IN: S. B. Saila (ed.). Fisheries and Energy Production: A Symposium. D. C. Heath & Co., Lexington, Mass. 300 pp.
- Merriman, D. and R. Sclar. 1952. The pelagic fish eggs and larvae of Block Island Sound. *Bull. Bingham Oceanogr. Coll.* 13(3):165-219.
- Merriner, J. V. 1976. Aspects of the reproductive biology of the weakfish, *Cynoscion regalis* (Sciaenidae), in North Carolina. *Fishery Bull.* 74:18-26.
- Miller, D. C. and A. D. Beck. 1975. Development and application of criteria per marine cooling waters. IN: Environmental effects of cooling systems at nuclear power plants (symposium). Proc. Intl. Atomic Energy Agency, Vienna, Aus. pp. 639-657.
- Morgan, R. P. and R. G. Stross. 1969. Destruction of phytoplankton in the cooling water supply of a steam electric station. *Ches. Sci.* 10(3 and 4):165-171.
- Normandeau Associates, Inc. 1973. New Haven Harbor Ecological Studies. New Haven, Connecticut. Ann. Rept. 1971-1972. Prep. for United Illuminating Co., New Haven, Connecticut. 208 pp.

- _____. 1974. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Ann. Rept. 1972-1973 for the United Illuminating Company, New Haven, Connecticut. 215 pp.
- Northeast Utilities Service Company. 1976. Millstone Nuclear Power Station Units 1, 2 and 3. Environmental Assessment of the Condenser Cooling Water Intake Structures 316(b) Demonstration.
- Pearcy, W. G. 1962. Ecology of an estuarine population of winter flounder, *Pseudopleuronectes americanus* (Walbaum). II. Distribution and dynamics of larvae. Bull. Bingham Oceanogr. Coll. XVIII:16-62.
- Pearcy, W. G. and S. W. Richards. 1962. Distribution and ecology of fishes of the Mystic River estuary, Connecticut. Ecology. 43(2): 248-259.
- Purdin. 1973. The population fluctuation of major adult copepods in Long Island Sound near Shoreham. Abstracts of the 6th Annual LIS conference -- Current research in an urban sea, Long Island Sound, N. Y. Ocean Sci. Lab., Montauk, New York.
- Richards, S. 1959. Pelagic fish eggs and larvae in Long Island Sound. IN: Oceanography of Long Island Sound. Bull. Bingham Oceanogr. Coll. 17(1):95-124.
- Smayda, T. J. 1958. Biogeographical studies of marine phytoplankton. Oikos. 9(2):158-191.
- Smith, W. G., J. D. Sibunka and A. Wells. 1978. Diel movements of larval yellowtail flounder, *Limanda ferruginea*, determined from discrete depth sampling. Fishery Bull. 76(1):167-178.
- Ulanowicz, R. E. 1975. The mechanical effects of water flow on fish eggs and larvae. pp. 77-88. IN: S. B. Saila (ed.). Fisheries and Energy Production: A Symposium. D. C. Heath and Co., Lexington, Mass. 300 pp.
- U.S. Environmental Protection Agency. 1977a. Guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment: Section 316(b). PL 92-500. 59 pp.
- _____. 1977b. Interagency 316(a) Technical Guidance Manual and Guide for Thermal Effects Sections of Nuclear Facilities Environmental Impact Statements. 79 pp.
- Warfel, H. E. and D. Merriman. 1944. Studies on the marine resources of southern New England. I. An analysis of the fish population of the shore zone. Bull. Bingham Oceanogr. Coll. 9(2):1-91.
- Warriner, J. E. and M. L. Brehmer. 1966. The effects of thermal effluents on marine organisms. Int. J. Air Water Pollut. 10:277-289.

- Wheatland, S. 1956. Pelagic fish eggs and larvae. IN: Oceanography of Long Island Sound, 1952-1954, Part VII. Bull. Bingham Oceanogr. Coll. 15:234-314.
- Wiebe, P. H., G. D. Grice and E. Hoagland. 1973. Acid-iron waste as a factor affecting the distribution and abundance of zooplankton in the New York Bight. II. Spatial variations in the field and implications for monitoring studies. Est. Coastal Mar. Sci. 1:51-64.
- Williams, G. C. 1968. Bathymetric distribution of planktonic fish eggs in Long Island Sound. Limnol. Oceanogr. 13(2):382-385.
- Yentsch, C. S. 1977. Plankton production. MESA New York Bight Atlas Monograph 12. New York Sea Grant Institute, Albany, N.Y. 25 pp.
- Zawacki, C. S. and P. T. Briggs. 1976. Fish investigations in Long Island Sound at a nuclear power station site at Shoreham, New York. NY Fish and Game J. 23(1):34-50.

APPENDIX 4.1

APPENDIX 4-1

COMPARABILITY OF ZOOPLANKTON COLLECTION METHODS

Scatter plots (Appendix Figure 4-1) and correlation coefficients (Appendix Table 4-1) demonstrate that there was little consistent relationship between density estimates derived from the Clark-Bumpus (CB) and 0.5 m net (1/2-meter) methods. It is our opinion that the larger diameter, larger-meshed (158 μ) 1/2-meter nets used since June 1975, provided estimates more representative of true population than did the previous method (12.5 cm, 76 μ m Clarke-Bumpus). The small CB net yielded different and erratic quantitative estimates compared to the 1/2 meter net. The larger net sampled larger volumes and was less susceptible to mesh clogging, which impairs filtering and flowmeter accuracy. The larger net was still sufficiently fine (158 μ m) to capture small zooplankters, such as veliger larvae of molluscs and copepod and barnacle nauplii.

Scatter plots and regression analyses for each of the 9 selected abundant species provide some information useful in comparing the validity of the two methods. Scatter plots demonstrate the lower limits of detection by each method and the frequency and densities at which one method was effective while the other was ineffective at catching each species. From the regression equation, a point of equivalence was calculated: this was the point at which both methods should provide equivalent density estimates (in the regression line equation, the case where $x = y$). For 1/2-m net density estimates below the equivalence point, comparable CB densities would be higher, while above this point CB estimates should be lower than 1/2-m density estimates. In general, the 1/2 m net had lower thresholds of detection by ten to one hundred times. Consistently with this, the 1/2-m net indicated presence while the CB net indicated absence more often than the reverse, for most species. Each species is discussed with respect to these factors. Considerations are based on Appendix Figure 4-1 and Appendix Table 4-1.

Acartia spp. copepodites were captured in the 1/2 m net on numerous occasions when they were absent from the CB sample. The CB net never captured *Acartia* copepodites in densities less than 125/m³; the larger net yielded density estimates as low as 3/m³. According to the regression equation, the CB estimate would be greater than the estimate provided by 1/2 m net at all times except during peaks of abundance (>8604/m³). The scatter plot, however, showed that the regression prediction was a poor approximation of the relationship between the methods, with an actual distribution spanning greater than two orders of magnitude around the regression line.

Acartia hudsonica was also more effectively captured by the 1/2 m net than by the CB; both capture rate and detection thresholds were favorable for the 1/2 m net. According to the regression equation, esti-

APPENDIX TABLE 4-1. COMPARABILITY OF ZOOPLANKTON COLLECTION METHODS: CORRELATION ANALYSIS.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	FAILURES TO CATCH ¹ (BY METHOD)	TOTAL TIMES CAUGHT ²	EQUIVALENCE POINT ³ CB = Z ₁	DETECTION THRESHOLD ⁴ (DENSITIES)	CORRELATION COEFFICIENT ⁵	REGRESSION EQUATION
<i>Acartia</i> copepodites	15	0	8,604/m ³	125/m ³	0.577	Log ₁₀ CB = Log ₁₀ (Z ₁ + 1) .556 + 1.747
<i>Acartia</i> hudsonica	26	3	1,355/m ³	200/m ³	0.571	Log ₁₀ CB = Log ₁₀ (Z ₁ + 1) .470 + 1.660
<i>Acartia</i> tonsa	12	15	3,247/m ³	200/m ³	0.602	Log ₁₀ CB = Log ₁₀ (Z ₁ + 1) .476 + 1.840
<i>Temora</i> longicornis	19	1	4,840/m ³	200/m ³	0.686	Log ₁₀ CB = Log ₁₀ (Z ₁ + 1) .524 + 1.754
Copepod copepodites	20	5	2,251/m ³	100/m ³	0.585	Log ₁₀ CB = Log ₁₀ (Z ₁ + 1) .370 + 2.112
Copepod nauplii	5	2	33,141/m ³	200/m ³	0.278	Log ₁₀ CB = Log ₁₀ (Z ₁ + 1) .239 + 3.440
Cirripedia nauplii	19	5	11,427/m ³	125/m ³	0.664	Log ₁₀ CB = Log ₁₀ (Z ₁ + 1) .482 + 2.102
Gastropod veligers	26	1	2,023/m ³	150/m ³	0.206	Log ₁₀ CB = Log ₁₀ (Z ₁ + 1) .147 + 2.820
Polychaete larvae	11	8	14,437/m ³	150/m ³	0.349	Log ₁₀ CB = Log ₁₀ (Z ₁ + 1) .329 + 2.791

¹Failures to catch by method indicated when other method yielded organisms.

²Total times caught by either one or both methods.

³Point at which both methods should provide equivalent density estimates.

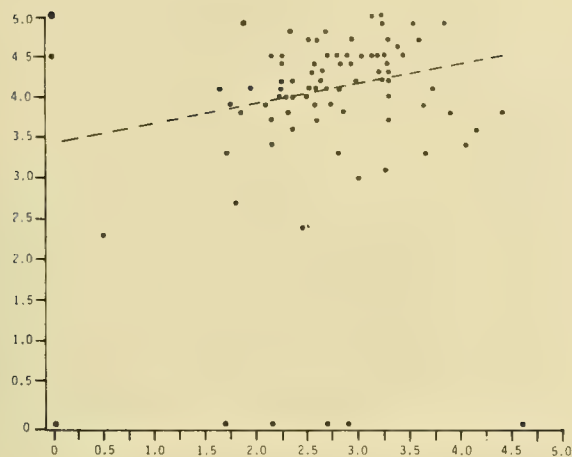
⁴Lowest detectable densities by method used.

⁵Based on data excluding those values which fell directly on x or y axis.

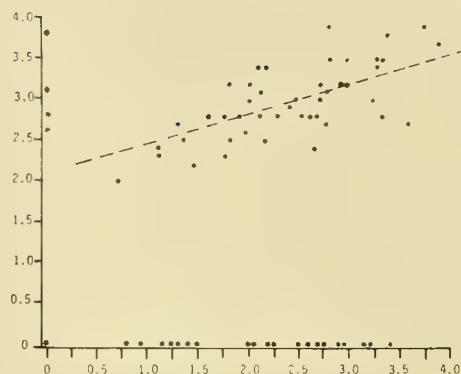
CB = Clarke-Bumpus

Z₁ = Sampling by 1/2 m #10 mesh net.

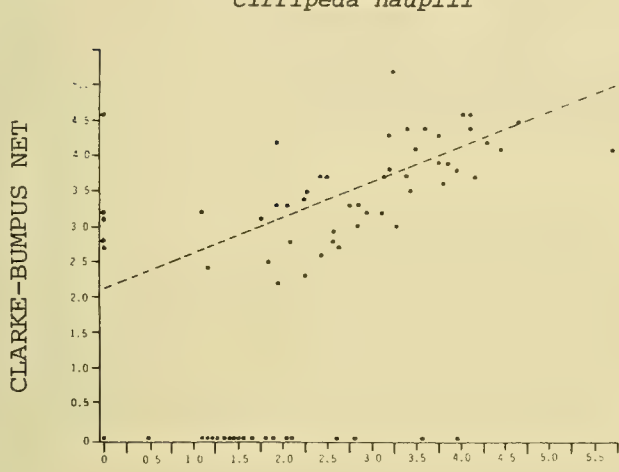
Copepod nauplii



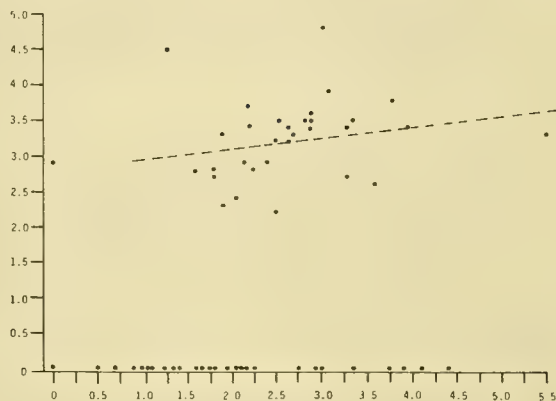
Copepod copepodites



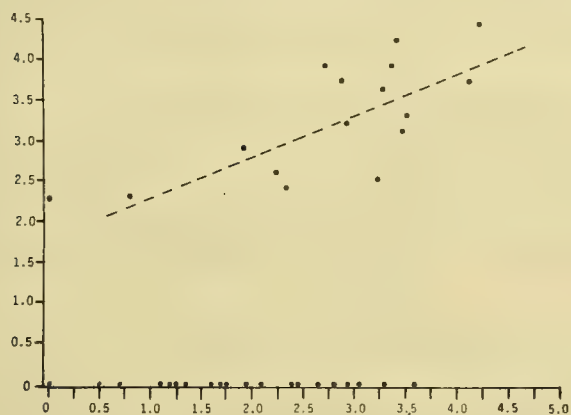
Cirripeda nauplii



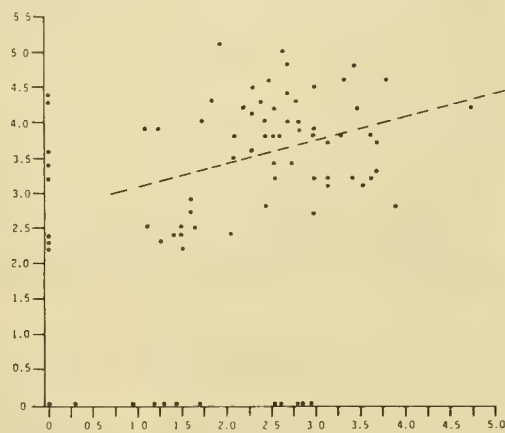
Gastropod veligers



Temora longicornis

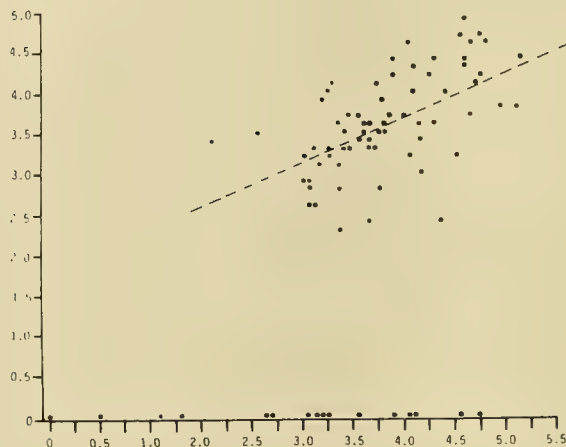
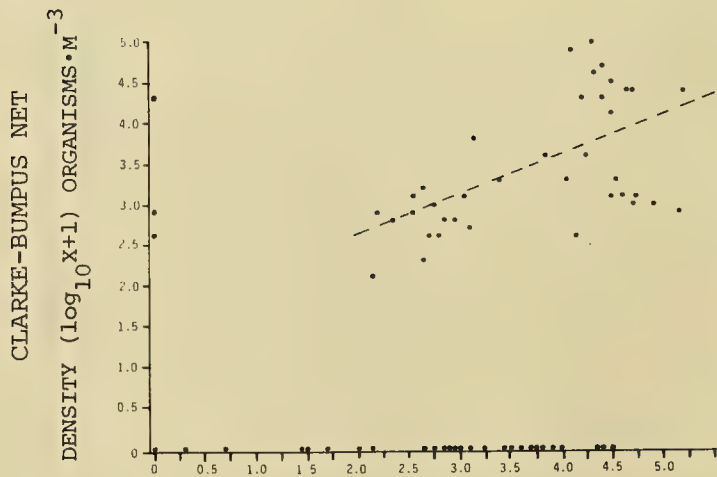
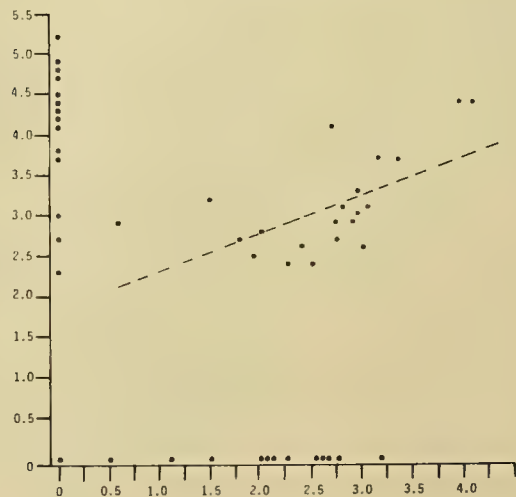


Polychaeta



$\frac{1}{2}$ METER NET DENSITY ($\log_{10} X+1$) ORGANISMS $\cdot M^{-3}$

Appendix Figure 4-1. Comparability of zooplankton collection methods: simple regression scatter plots. New Haven Harbor Ecological Studies Summary Report, 1979.

Acartia copepodites*Acartia hudsonica**Acartia tonsa*

$\frac{1}{2}$ METER NET DENSITY (log₁₀ X+1) ORGANISMS • M⁻³

mates of density would be higher for the 1/2 m net during spring peaks and somewhat lower than CB-estimated densities when less than 1355/m³ occurred according to both methods. The scatter plot showed that the regression line was based on few erratically distributed points.

Acartia tonsa was detected in lower densities by the 1/2 m net than by the CB and had an equivalence point just less than midsummer peak densities. Presence/absence differences between the methods were peculiar, in that, when CB samples indicated densities greater than 5000/m³, 1/2 m net samples generally indicated absence. The reverse occurred at 1/2 m net densities below 400/m³. Thus, CB samples produced high estimates of peak abundance and low estimates at other times. This scatter plot showed that a small number of poorly related points contributed to the regression.

Temora longicornis was captured twice as frequently by the 1/2 m net and was only caught by both methods on 15 occasions, clearly showing that the CB net was relatively ineffective for this species. The equivalence point was above most peaks of abundance, so that, when captured by the CB net, this method gave the higher density estimate. However, because of the paucity and scatter of points, there is little reason to have faith in the regression equation.

Copepod copepodites were more effectively sampled by the 1/2 m net, as shown by capture frequency and detection threshold. Also, at densities below 2251/m³ the CB net gave higher density estimates than the 1/2 m net; such densities were exceeded only during major spring or fall abundance peaks as measured by the CB net. Although some evidence of linearity was apparent in the scatter-plot, many of the points plotted were nearly an order of magnitude removed from the regression line.

Copepod nauplii were sampled similarly by the two methods in terms of detection thresholds; presence/absence disagreements were few. The equivalence point was exceptionally high, near the absolute peak of abundance, and was rarely exceeded by the CB net and never by the 1/2 m net. Scatter was substantial and the plot showed no real linear tendency.

Cirripedia nauplii were more frequently captured by the 1/2 m net than by the CB net (Table 4-4); this was attributable to the numerous catches by the 1/2 m net at densities below the threshold of detection for the CB net. As with copepod nauplii, the equivalence point was high (11,427/m³) and corresponded to sporadic and infrequent abundance peaks. While scatter was great, a distinct linear tendency was apparent.

Gastropod veligers were captured far more frequently and effectively by the 1/2 m net; on 26 occasions low densities were indicated by the 1/2 m net which were undetected by the high-threshold CB method. Gastropod larvae were rarely more dense than the equivalence value of 2023/m³, and were thus estimated as more abundant (when captured) by the CB net. Linearity was not apparent in the scatter-plot.

Polychaete larvae were fairly effectively sampled by both methods, although both indicated absence a number of times when contradicted

by the other method. As with all other taxa, the 1/2 m net had the lower detection threshold; like copepod and Cirripedia nauplii, the high equivalence value ($14,437/\text{m}^3$) was exceeded only in peaks of abundance. The scatter-plot was distinctly non-linear and deviation from the regression line by an order of magnitude or more was common.

To summarize the comparability study results, it was clear that the two methods yielded radically different density estimates. We believe that the CB method was less accurate, underestimating most taxa when densities were near or below detection threshold densities ($100\text{--}200/\text{m}^3$) and overestimating peak densities, which were generally those in excess of the equivalence value (Appendix Table 4-1). Underestimates are attributed to patchiness of the zooplankton assemblage and low sample volumes from the small net; overestimates are explained by patchiness and inaccuracies in the estimation of sample volume. Since the CB and 1/2-meter net sample different volumes of water they are likely to result in different estimates of population densities that are reflective of the dispersion characteristics of the species being sampled. Both methods are also limited in accuracy by net clogging and by the error resulting from subsampling in the laboratory. We conclude that the 1/2-meter net was the best practical sampling method for application to zooplankton assemblages of New Haven Harbor. The Clarke-Bumpus net did not meet the basic guideline for plankton sampling recommended by EPA (1973).

APPENDIX TABLE 4-2. SPECIES LIST OF ICHTHYOPLANKTON IDENTIFIED FROM NEW HAVEN HARBOR COLLECTIONS FROM 1974 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	EGGS							LARVAL						
	1971	1972	1973	1974	1975	1976	1977	1971	1972	1973	1974	1975	1976	1977
Anguillidae <i>Anguilla rostrata</i>								X				X	X	X
Clupeidae <i>Alosa</i> sp. <i>Brevoortia tyrannus</i> <i>Clupea</i> spp. <i>C. harengus</i>				X	X	X	X	X X X	X		X	X	X	X
Engraulidae <i>Anchoa</i> sp. <i>A. hepsetus</i> <i>A. mitchilli</i>										X		X	X	X
Osmeridae <i>Osmerus mordax</i>							X							X
Gadidae <i>Enchelyopus cimbrius</i> <i>Gadus morhua</i> <i>Merluccius</i> sp. <i>M. bilinearis</i> <i>Microgadus tomcod</i> <i>Urophycis</i> sp. <i>U. chuss</i>					X	X	X	X X	X			X	X	X
Cyprinodontidae <i>Fundulus</i> sp.								X						X
Atherinidae <i>Menidia</i> sp. <i>M. menidia</i>								X	X		X	X	X	X
	EGGS							LARVAE						
	1971	1972	1973	1974	1975	1976	1977	1971	1972	1973	1974	1975	1976	1977
Gasterosteidae <i>Gasterosteus aculeatus</i>														X
Syngnathidae <i>Hippocampus erectus</i> <i>Syngnathus fuscus</i>					X			X	X		X	X	X	X
Sparidae <i>Stenotomus</i> spp. <i>S. chrysops</i>					X							X	X	X
Sclaeinidae <i>Cynoscion regalis</i> <i>Menticirrhus saxatilis</i>				X	X		X	X				X		X
Labridae <i>Tautoga onitis</i> <i>Tautogolabrus adspersus</i>				X	X	X		X X	X		X	X	X	X
Stichaeidae <i>Lumpenus lumpretaeformis</i>													X	
Pholidae <i>Pholis gunnellus</i>						X		X				X	X	X
Ammodytidae <i>Ammodytes</i> sp.									X	X	X	X	X	X
Gobiidae <i>Gobiosoma ginsburgi</i>										X	X		X	X
Scombridae <i>Scomber scombrus</i>					X	X	X					X	X	X

(Continued)

APPENDIX TABLE 4-2. (Continued)

	EGGS							LARVAE						
	1971	1972	1973	1974	1975	1976	1977	1971	1972	1973	1974	1975	1976	1977
Stromateidae <i>Peprilus triacanthus</i>								X			X	X		X
Triglidae <i>Prionotus</i> spp.				X	X	X	X				X			X
Cottidae <i>Myoxocephalus</i> sp. <i>M. aeneus</i>								X	X	X	X	X	X	X
Cyclopteridae <i>Liparis</i> sp.														X
Bothidae <i>Etropus microstomus</i> <i>Paralichthys dentatus</i> <i>P. oblongus</i> <i>Scophthalmus aquosus</i>							X				X	X	X	
Pleuronectidae <i>Limanda ferruginea</i> <i>Pseudopleuronectes americanus</i>				X			X	X	X	X		X	X	X
Soleidae <i>Trinectes maculatus</i>						X	X					X	X	
Tetradontidae <i>Sphaeroides maculatus</i>												X	X	X
Unidentified				X	X	X	X						X	
Labridae/ <i>Limanda ferruginea</i> <i>Urophycis/Enchelyopus/Peprilus</i> <i>Enchelyopus/Merluccius</i> <i>Urophycis/Merluccius</i> <i>Scophthalmus/Paralichthys</i>				X	X	X	X							

X = Present

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

5.0 EXPOSURE PANELS

by C. Drew Harvell
Kenneth A. Simon and Andrew J. McCusker

Normandeau Associates, Inc.
Bedford, N. H.

TABLE OF CONTENTS

	PAGE
<i>INTRODUCTION</i>	5-1
<i>METHODS</i>	5-2
<i>CHARACTERIZATION OF THE NEW HAVEN HARBOR EXPOSURE</i>	
<i>PANEL COMMUNITY</i>	5-7
<i>Characteristic Taxa</i>	5-20
<i>Selected Taxa</i>	5-20
<i>COMPARISON OF NEW HAVEN HARBOR WITH OTHER LONG ISLAND</i>	
<i>SOUND SITES</i>	5-37
<i>ANALYSIS OF IMPACTS OF NEW HAVEN HARBOR STATION OPERATION</i> . . .	5-41
<i>SUMMARY</i>	5-43
<i>LITERATURE CITED</i>	5-50

LIST OF FIGURES

		PAGE
5-1.	Location of three exposure panel stations within New Haven Harbor	5-4
5-2.	Configuration of exposure panel array and construction of exposure panels	5-4
5-3.	Settlement times of abundant taxa on short-term panels by month, from July 1971 through October 1977.	5-8
5-4.	Species richness by month and by station for long-term panels, August 1971 through October 1977, with mean monthly water temperatures.	5-11
5-5.	Species on long-term panels by station and by year, August 1971 through October 1977	5-12
5-6.	Abundance of <i>Balanus crenatus</i> by year and by station, for years present, August 1971 through October 1977. . .	5-21
5-7.	Abundance of <i>Balanus</i> spp. by year and by station, for years present, August 1971 through October 1977. . . .	5-21
5-8.	Abundance of <i>Balanus improvisus</i> by year and by station, August 1971 through October 1977	5-22
5-9.	Abundance of <i>Balanus eburneus</i> by year and by station, August 1971 through October 1977	5-23
5-10.	Abundance of <i>Obelia longissima</i> by year and by station, August 1971 through October 1977	5-24
5-11.	Abundance of <i>Polydora</i> spp./mudworm tubes by year and by station, August 1971 through October 1977	5-25
5-12.	Abundance of <i>Corophium insidiosum</i> by year and by station, August 1971 through October 1977.	5-26
5-13.	Abundance of <i>Teredo navalis</i> by year and by station, August 1971 through October 1977	5-27
5-14.	Abundance of <i>Mytilus edulis</i> by year and by station, August 1971 through October 1977	5-28

LIST OF TABLES

	PAGE
5-1. TOTAL NUMBER OF MONTHS LONG-TERM PANELS SUBMERGED	5-5
5-2. SPECIES RICHNESS ON SHORT-TERM PANELS BY MONTH, AUGUST 1971 THROUGH OCTOBER 1977.	5-10
5-3. HIGHEST TAXA DISTRIBUTION OVER STATION FOR SHORT- AND LONG-TERM PANELS COMBINED	5-13
5-4. CHARACTERISTIC TAXA DISTRIBUTIONS BY YEAR AND BY STATION (SHORT- AND LONG-TERM COMBINED)	5-18
5-5. PERCENT OCCURRENCE OF ALL TAXA ON LONG-TERM PANELS AT EACH STATION, AUGUST 1971 THROUGH OCTOBER 1977.	5-19
5-6. FAUNAL SPECIES PRESENT AT SELECTED LOCATIONS IN LONG ISLAND SOUND	5-38
5-7. CHARACTERISTIC TAXA PRESENT AT NEW HAVEN HARBOR AND MILLSTONE HARBOR 1977	5-40
5-8. SPECIES DISTRIBUTION (BY STATION) FOR SHORT-AND LONG- TERM PANELS COMBINED.	5-44

5.0 EXPOSURE PANELS

by C. Drew Harvell, Kenneth A. Simon and Andrew McCusker

Normandeau Associates, Inc.
Bedford, N. H.

INTRODUCTION

Submerged hard substrates become overgrown by plant and animal assemblages known as fouling communities. Hydroids, mussels, tunicates, and marine borers are the predominant community constituents, while motile species form a more transient component of the assemblage. Epibiotic communities may accelerate deterioration of wooden structures or foul power station cooling systems and ship bottoms (Battelle, 1977). Exposure panels of various sizes and materials have been widely used for the study of fouling communities (Pomerat and Weiss, 1946).

The exposure panel component of the New Haven Harbor Station Ecological Monitoring Studies was designed to evaluate the impact of the generating station operations on abundance, distribution, and seasonal patterns of populations attached to artificial substrates in New Haven Harbor. Information concerning the abundance and distribution of fouling organisms in New Haven Harbor was collected preoperationally, (July 1970 through July 1975), and operationally (July 1975 through October 1977) as part of The United Illuminating Company's baseline and monitoring programs. These data have been presented and evaluated in a series of reports prepared from 1970 through the current year (Raytheon, 1970a, 1970b, 1971; NAI, 1973a, 1974a, 1974b, 1975a, 1976a, 1977a, 1978).

Fouling organisms were sampled on short- (1-month) and long-term (1-year) exposure panels. Short-term panels provide information regarding times and lengths of reproductive periods for species colonizing relatively bare panel surfaces. Long-term panels yield information on temporal sequences as well as seasonal growth patterns

of colonizing species. Species that do not settle on short-term panels due to absence of proper "niche" may settle on long-term panels and contribute to the development of the fouling community.

Fouling-panel studies can be particularly effective in determining the extent of impact of a thermal discharge. Settlement times and community composition are intricately related to water temperature (Naylor, 1965; Osman, 1977); consequently, thermal addition may alter spawning and settling periods as well as differentially affecting growth rates. Panel studies are also an effective measure of availability of recruitable larvae, a parameter potentially influenced by entrainment in the power station cooling water intake system. Enright (1977) suggested that although numerous, the number of larvae entrained is not ecologically significant in most cases, and that panel surveys provide the most conclusive information on the subject.

The monitoring program was designed to characterize the normal New Haven Harbor community as well as to detect any impact of the power station on the community. The section entitled "Characterization of Community" discusses natural, seasonal and annual fluctuations as well as spatial variations in dominant species distribution. These parameters are compared with other sites in Long Island Sound.

Potential modes of power station impact are examined in the "analysis of impact" section. These parameters are considered with reference to the New Haven Harbor community, utilizing information from other thermal impact studies in Long Island Sound. Data from preoperational and operational periods are compared to detect presence or absence of impact.

METHODS

Exposure panels were maintained at Long Wharf, the New Haven Harbor Station pier (referred to as the Coke Works Pier prior to 1976)

and on a dolphin off Fort Hale Park in New Haven Harbor (Figure 5-1). The New Haven Harbor Station pier site is closest to the thermal plume, and is in close proximity to Station 9, sampled monthly as part of the hydrographic program (Figure 5-1). A special survey (NAI, 1977b) revealed that the thermal plume from Harbor Station could occasionally intersect Stations 8 and 9 with a temperature increase above ambient of 0.5-1.0°C.

A rack containing a series of horizontal 3-1/2" x 10" x 3/4" asbestos-faced pine panels was installed at each site one meter below the approximate spring low-tide level (Figure 5-2). Each month from July 1971 through October 1977 two panels were removed from each station: a short-term panel that had been exposed for 1 month and a long-term panel that had normally been submerged for 12 months (Table 5-1). Two new panels were installed each month to replace those removed. During the first year of the program (1971), long-term panels were removed after the second month and every month thereafter until the twelfth month. Consequently, until the study was a year old (July 1972), long-term panels showed a monthly progression of colonization and growth, rather than a twelve-month accumulation of species. This was also true on panels replaced after destruction of the panel arrays by storms and ice (September 1976; March 1977). Sampling occurred each month from 1971 through 1977 except where indicated in Table 5-1.

After collection, each panel was placed in a container with sea water and refrigerated for not more than three days prior to identification. (Prior to 1976, panels were wrapped in wet newsprint and refrigerated before placement in individual running seawater baths). Enumeration and size observations were made on all macroscopic epifauna attached to the asbestos panel, and from July 1976 through October 1977 color photographs were made of each panel. Wooden blocks were scraped clean and examined for boring organisms.

The experimental regime of 12-month long-term and 1-month short-term panels was selected in New Haven Harbor to provide infor-

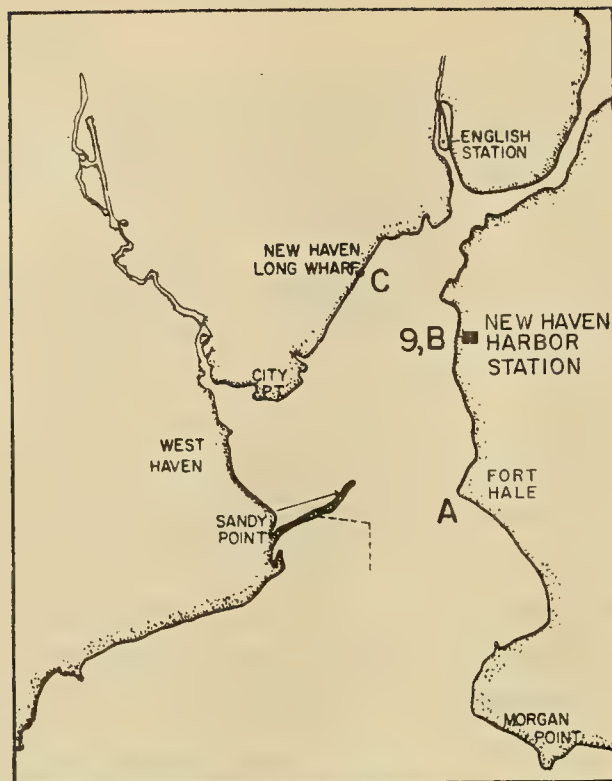


Figure 5-1. Location of three exposure panel stations within New Haven Harbor at (A) Fort Hale, (B) New Haven Harbor Station and (C) Long Wharf, with hydrographic Station 9. New Haven Harbor Ecological Studies Summary Report, 1979.

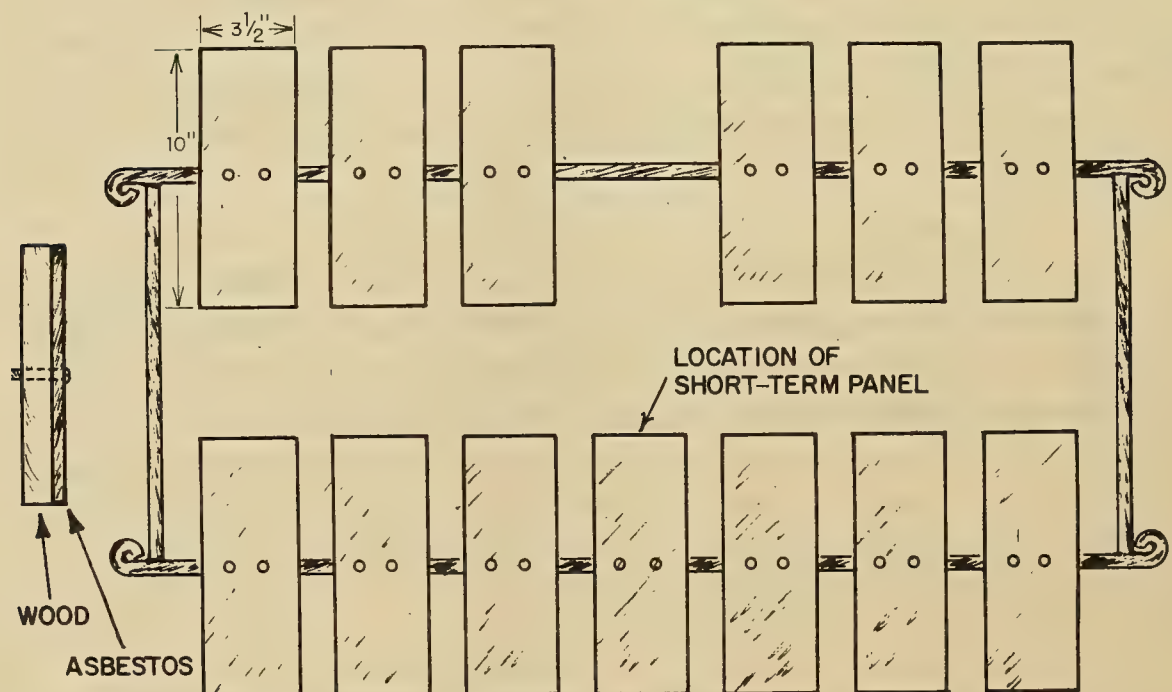


Figure 5-2. Configuration of exposure panel array and construction of exposure panels (mounted with asbestos side away from iron frame). New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 5-1. TOTAL NUMBER OF MONTHS LONG-TERM PANELS SUBMERGED. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

[illegible]

mation relevant to a thermal impact study and the most useful comparative information relative to greater Long Island Sound. This type of program yields information concerning time and length of larval recruitment periods and "climax community" compositions. The short-term panels provide a good indication of times of reproductive activity in panel assemblage members, which is usually dependent upon water temperature (Cory and Nauman, 1969; Osmann, 1977). Information on temporal progression of the community is not available through the study design.

Data are presented as recorded but may not always consistently reflect the actual situation due to personnel changes in May 1975 and July 1976. After May 1975 attempts were made to improve the accuracy of the data; estimation techniques for percent cover of hydroids changed in May 1976, along with the addition of a verified reference collection. Greater emphasis was placed on the identification and enumeration of smaller organisms. In some cases the use of absolute numbers replaced percent cover estimations; all animals are currently enumerated except for colonial hydroids, tunicates and bryozoans. To ensure no loss of data comparability due to the contractor change in 1976, efforts were made to improve the level of identification to the species level. In 1976, specific, generic and familial level identifications were reported. Seventeen of the higher taxa were replaced in 1977 by more precise nomenclature. For example, in 1976, mudworm tubes, *Polydora* spp. and *P. ligni* were recorded, but in 1977 more careful identification established that only *P. ligni* was present. Because species richness is strongly influenced by this type of change, its usefulness in the study is limited. The emphasis in determining the nature of the fouling panel community is more reliably directed to a consideration of the species which occur frequently or abundantly in the harbor.

Similar sampling methods were used on other fouling-panel studies conducted in the Long Island Sound area (Niantic Bay and Stamford Harbor; Battelle, 1978 and NAI, 1974c respectively). Studies in Bridgeport Harbor (NAI, 1973b) utilized different techniques: 3" x 3" glass panels that were fixed in one percent formalin immediately after

collection. Samples collected at one site each in Bridgeport and New Haven Harbor during a 1935 survey (Clapp, 1937) used nine 4" x 4" x 6" pine blocks attached to a wooden board. The exposure scheme in the 1935 survey was similar to the present study in that each month two blocks were removed and replaced (long-term and short-term); the longest long-term block was on site from February-November 1935. Stamford Harbor long-term panels (1971-1973, NAI, 1974c) were sampled to describe temporal succession from the period of initial exposure (Panel number 2 removed after 2 months exposure, Panel number 3 after 3 months... Panel number 12 after 12 months).

CHARACTERIZATION OF THE NEW HAVEN HARBOR EXPOSURE PANEL COMMUNITY

The New Haven Harbor fouling community observed on exposure panels was similar in terms of dominant taxa, species richness, temporal variability and spatial distribution over all years of the study (NAI, 1978). The long-term fouling community was dominated by barnacles (*Balanus* spp.), hydroids (*Obelia longissima*), mussels (*Mytilus edulis*), marine borers (*Teredo navalis*), mudworms (*Polydora ligni*), and tube-dwelling amphipods (*Corophium insidiosum*). Dominance was determined by percent occurrence and abundance over all years. (Percent occurrence values were calculated by dividing the total number of times an organism appeared at a given station by the number of samples taken over the seven-year period at that station.) Most taxa exhibited seasonal fluctuations in abundance related to spawning and settlement. Long-term panels did not show clear seasonal patterns. In some years, high summer species-richness values on long-term panels occurred (1977), but spring or fall maxima were equally prevalent over the entire seven-year study period (Figure 5-4). The number of taxa was usually lower at Long Wharf than Harbor Station or Fort Hale.

The short-term fouling community was dominated (>3-4 yrs presence) by *Obelia* spp., *Nereis succinea*, *Balanus eburneus*, and *Mytilus edulis*. Seasonal distributions are a function of reproductive timing

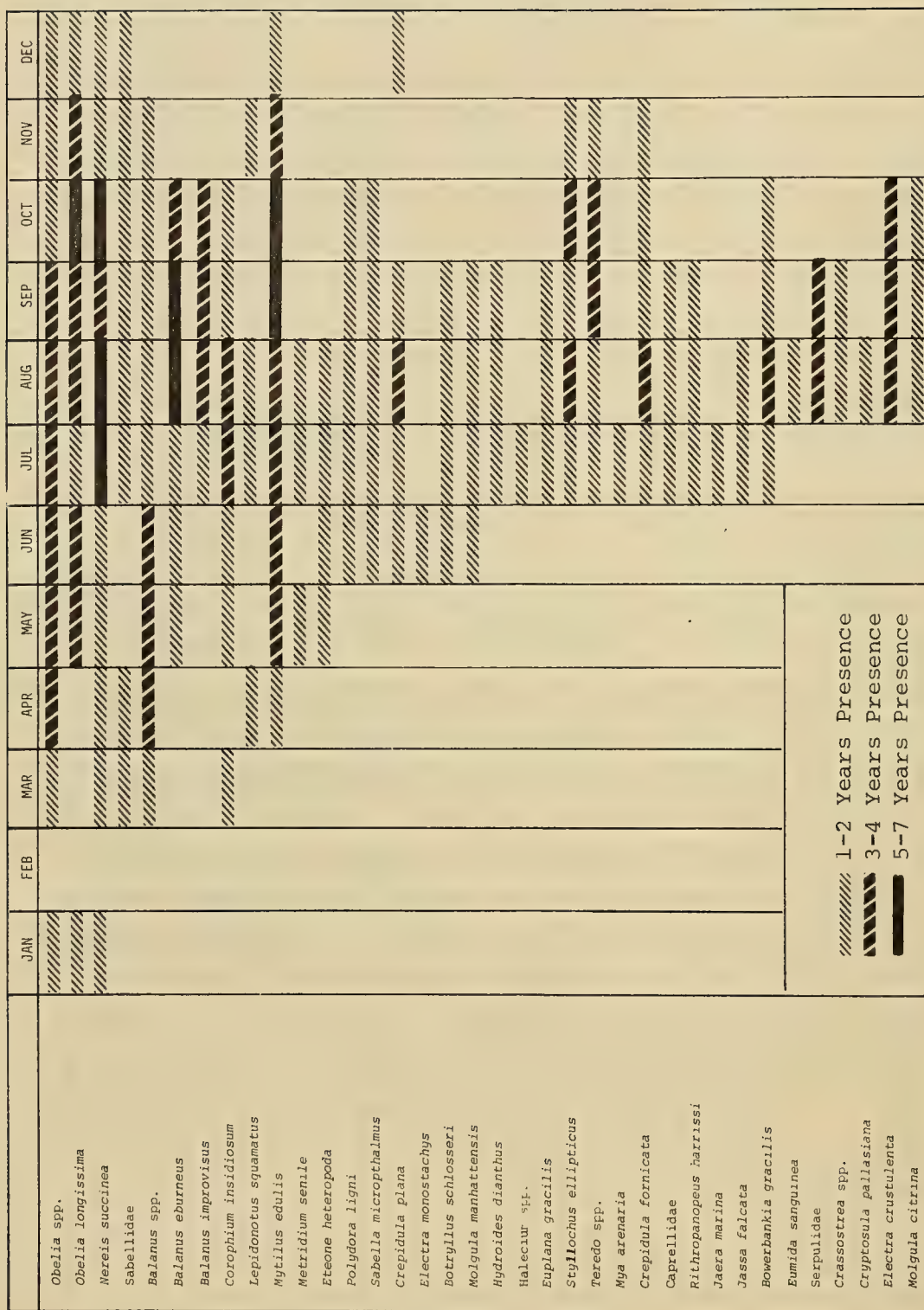


Figure 5-3. Settlement times of abundant* taxa on short-term panels by month, from July 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

* Species occurring at all stations for at least one year and at an overall percent occurrence greater than 3.5% (Table 5-1).

with most species settling from June through October (Figure 5-3). Species richness values were greatest in July, August and September for all years (Table 5-2). Species richness was usually lower at Long Wharf than Fort Hale or Harbor Station, reflecting decreased water quality in the inner harbor.

Species richness on long-term panels showed annual increases from 1971 through 1976 and a decrease in 1977 (Figures 5-4, 5-5). As already indicated, however, this parameter is influenced by taxonomic refinements, panel losses and length of sampling period. Table 5-3 was constructed to assess the effect of 1975 and 1976 taxonomic changes on the data. Species are included in the highest taxon that could have been used at any time. For example, in some years barnacles were identified to *Balanus* spp., consequently more specific taxa, *B. eburneus*, *B. crenatus* and *B. improvisus* are grouped under *Balanus* spp. and times of occurrence noted. Many of the polychaete species have been grouped in families as the lowest meaningful taxon, while in some cases the class designation Polychaeta was used. Taxa are marked to indicate changes in identification resulting from the 1975 personnel change, as well as changes instituted with the new contractor in 1976. The latter have a limited impact on Table 5-3 data because the changes are largely refinements of previously identified taxa. Figure 5-4, however, shows a large 1976 species richness increase reflecting an increase in more specific taxa, accompanying the previously used general classifications, but this increase is not a true indication of an actual species richness increase. The 1977 decrease is related to long-term panel loss at Fort Hale, and the shortened sample period (10 months) as well as taxonomic refinements.

Seasonal trends in long-term panel species richness were variable in New Haven Harbor. High summer richness occurred in the summer of 1977, but not in 1975 and 1976, and was probably a function of recruitment from spawning populations (Osman, 1977). The general trend of unpolluted estuaries is toward high summer richness (Calder and Brehmer, 1967; NAI, 1975b; NUSCO, 1977), but this trend may be vari-

TABLE 5-2. SPECIES RICHNESS ON SHORT-TERM PANELS BY MONTH, AUGUST 1971 THROUGH OCTOBER 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

SHORT TERM PANELS													
Fort Hale	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
1971								6	2	5	2	1	6
1972	1	0	0	0	3	2	2	7	4	3	2	1	9
1973	1	0	0	2	0	2	0	3	6	3	3	0	7
1974	2	0	1	0	4	5	1	4	5	6	1	1	12
1975	1	0	0	0	4	2	5	7	14	10	1	1	19
1976	ND	1	ND	3	2	3	6	10	ND	ND	0	0	18
1977	0	0	ND	ND	0	2	19	13	2	4	0	0	21
Harbor Station													
1971								4	2	4	1	1	7
1972	1	0	0	0	2	3	2	3	3	2	2	0	7
1973	3	0	0	1	3	1	5	3	2	0	3	2	12
1974	0	0	0	1	2	3	3	8	6	5	2	1	8
1975	1	0	1	1	7	4	9	5	11	7	1	0	26
1976	0	0	3	1	0	4	11	13	17	7	1	0	28
1977	0	0	0	1	0	1	17	22	4	1	0	0	30
Long Wharf													
1971								3	0	3	3	0	5
1972	0	0	0	0	1	2	2	2	1	1	1	0	3
1973	1	0	0	0	0	2	4	2	3	3	1	1	6
1974	1	0	0	1	3	2	1	3	6	3	1	0	8
1975	0	0	0	0	5	2	4	3	10	2	0	0	17
1976	0	0	3	1	1	2	5	10	11	4	0	0	19
1977	0	0	0	1	0	1	7	10	3	0	0	0	14

ND = No Data

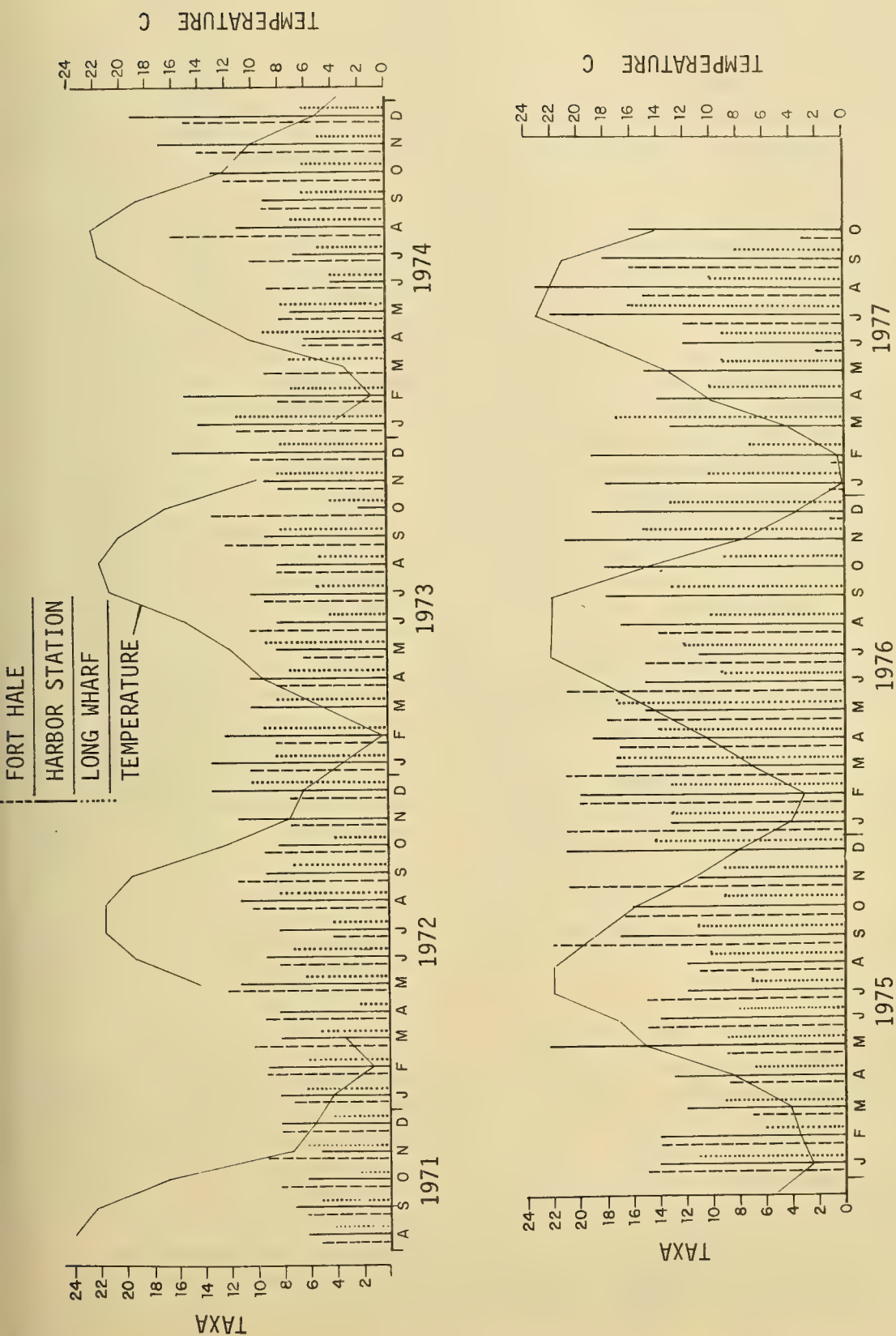


Figure 5-4. Species richness by month and by station for long-term panels, August 1971 through October 1977, with mean monthly water temperatures.
New Haven Harbor Ecological Studies Summary Report, 1979.

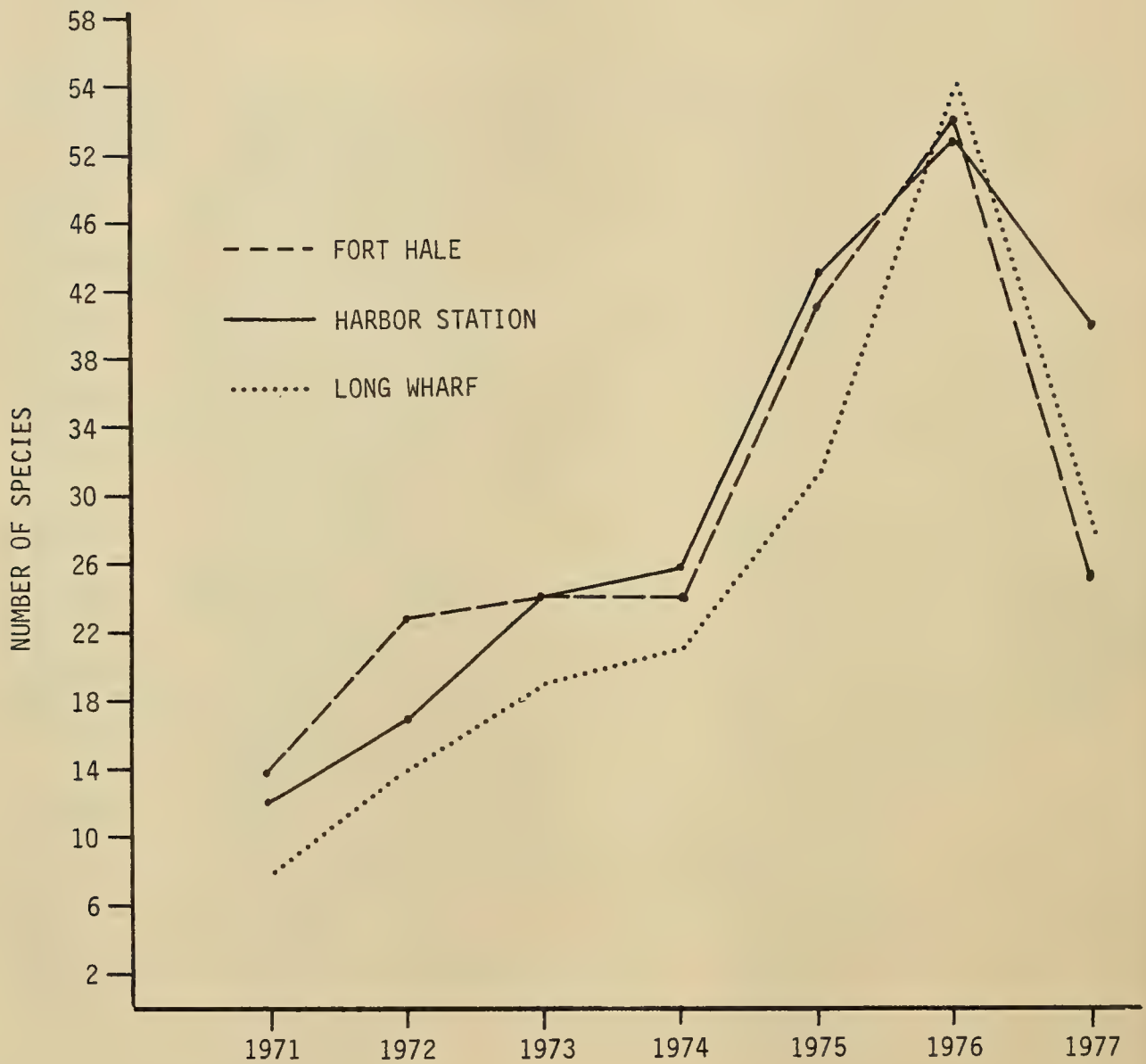


Figure 5-5. Species richness on long-term panels by station and by year, August 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 5-3. HIGHEST TAXA DISTRIBUTION OVER STATION FOR SHORT-AND LONG-TERM PANELS COMBINED.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

TAXA	○ 1975 personnel change			□ 1976 contractor change					
	1971	1972	1973	1974	1975	1976	1977		
	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW		
ALGAE									
Chlorophyceae			x		x	x x			
<i>Polysiphonia</i> spp.					x				
PORIFERA									
Unidentified porifera									
<i>Halichondria bowerbanki</i>					x	x			
CNIDARIA									
<i>Halecium</i> spp.			x		x				
<i>Obelia</i> spp.	x x	x x	x x	x x	x x	x x	x x		
Unidentified Anthozoan		x x	x x	x x	x x	x x	x x		
ANNELIDA									
<i>Nereis</i> spp.	x x	x x	x x	x x	x x	x x	x x		
Phyllodocidae				x x	x x	x x	x x		
<i>Podarke obscura</i>				x x		x x	x x		
Polynoidae		x	x x	x x		x x	x x		
Sabellidae		x	x x	x x	x x	x x	x x		
<i>Sabellaria vulgaris</i>			x x	x x	x x	x x	x x		
Serpulidae		x	x x	x x	x x	x x	x x		
Spionidae			x x	x x	x x	x x	x x		
<i>Stauronereis rudolphi</i>				x	x	x	x		
Syllidae					x	x	x		
Terebellidae			x			x			
MOLLUSCA									
<i>Crassostrea</i> sp.	x x	x x	x x	x x	x x	x x	x x		
<i>Crepidula</i> spp.	x x	x x	x x	x x	x x	x x	x x		

Continued

TABLE 5-3. (Continued)

○ 1975 personnel change □ 1976 contractor change

TAXA	1971	1972	1973	1974	1975	1976	1977
	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW
<i>Doridella obscura</i>					⊗		x
<i>Littorina saxatilis</i>							
<i>Mitrella lunata</i>			x				x
<i>Mya arenaria</i>			x		x	x	x
<i>Mytilus edulis</i>		x	x	x	x	x	x
<i>Nucula</i> spp.						⊗	
Teredinidae	x	x	x	x	x	x	
<i>Thracia septentrionalis</i>		x	x				x
<i>Urosalpinx cinereus</i>				x	x	⊗	
Acarina							
CRUSTACEA (ISOPODA)							
<i>Jaera marina</i>		x					x
<i>Limnoria</i> spp.					x		
(CIRRIPEDIA)							
<i>Balanus</i> spp.	x	x	x	x	x	x	x
(AMPHIPODA)							
Aorid amphipod							
Caprellidae		x			x	x	x
<i>Corophium</i> spp.	x	x	x	x	x	x	x
Gammaridea		x		x	x	x	x
Ischyroceridae	x			x		x	

TABLE 5-3. (Continued)

5-15

	○ 1975 personnel change □ 1976 contractor change											
	1971	1972	1973	1974	1975	1976	1977					
	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW					
<i>Jassa falcata</i>					x	⊗	⊗	x	x			
<i>Melita dentata</i>										x	x	x
<i>Melita nitida</i>										x	x	x
(DECAPODA)												
<i>Cancer irroratus</i>												
<i>Eurypanope depressus</i>					x	⊗	⊗					
<i>Hexopanopeus angustifrons</i>												
<i>Neopanope texana</i>			x	x	x	x	x	x	x	x	x	x
<i>Palaemonetes</i> spp.					⊗	x*						
<i>Panopeus herbstii</i>		x	x	x	x	x	x	x	x	x	x	x
<i>Rithropanopeus harrissi</i>						⊗	⊗	⊗	⊗	⊗	⊗	⊗
ECTOPROCTA												
<i>Alcyonidium polyoum</i>												
<i>Bowerbankia gracilis</i>	x	x	x	x				x	x	x	x	x
<i>Bugula turrita</i>												
<i>Cryptosula pallasiana</i>												
<i>Electra crustulenta</i>	x	x	x	x	x	x	x	x	x	x	x	x
<i>Electra monostachys</i>								⊗	⊗			
<i>Schizoporella unicornis</i>					x			x	x			
ECHINODERMATA												
<i>Asterias forbesii</i>			x					x				
CHORDATA												
<i>Botryllus schlosseri</i>												
<i>Molgula</i> spp.	x	x	x	x	x	x	x	x	x	x	x	x
Number of Taxa	10	9	6	17	14	11	19	21	20	12	9	25
Number of Taxa (Stations Combined)	11							25	26			32

* *P. herbstii* and *R. harrissi* were lumped as one taxa in species richness count.

able. Cory and Nauman (1963) found reduced numbers and high mortality in a Patuxent River Estuary thermal effluent discharge canal in August, although the same canal showed high summer species richness the following August.

Settlement on short-term panels usually began in March, with most taxa present in July, August and September as a function of spring and summer recruitment; settlement declined thereafter (Figure 5-3, Table 5-2). Settlement followed the same general sequence of epifaunal dominants as in a North Carolina estuary discussed by Dean & Bellis (1975), with barnacles and hydroids settling in the spring, bryozoans in the summer, and a smaller set of barnacles in the fall. An increase in short-term panel species richness values from 1971 through 1977 was probably a result of taxonomic refinements, but could also be indicative of some water quality improvements as was the case with species diversity at Niantic Bay (Battelle, 1978). For most years, settlement on short-term panels was greater at New Haven Harbor Station and Fort Hale than Long Wharf, probably reflecting deteriorated water quality at Long Wharf (Table 5-2).

During most years of the study, certain trends in spatial distribution were evident. Species richness values were lower at Long Wharf on short-term panels for all years and on long-term panels for all years except 1976 and 1977 (Table 5-2, Figure 5-5). The apparent reversal of this trend in 1977 is probably accounted for by the loss of the panel array at Fort Hale that year and resultant immaturity of the communities on Fort Hale long-term panels that were examined. Decreasing richness from outer to inner harbor is characteristic of polluted estuaries (Calder and Brehmer, 1967) and was also seen in Bridgeport and Stamford Harbors (NAI, 1973b, 1974c). Long Wharf generally showed a reduced salinity (from 1 to 4 ‰ depending on tide and season) due to its proximity to the freshwater influx of the Mill and Quinnipiac Rivers (NAI, 1977a). This may reduce the number of species occurring there.

Table 5-4 shows, by year and station, the distribution of characteristic species on short- and long-term panels (present at all stations for at least one year and with a total percent occurrence over all panels and years of greater than 3.5%). The following species were present for all years at most stations: *Balanus eburneus*, *Obelia longissima*, *Styllocheus ellipticus*, *Crepidula fornicata*, *Nereis succinea*, *Electra crustulenta*, and *Corophium insidiosum*. This consistent occurrence resulted in high percent-occurrence values irrespective of absolute quantity (Table 5-5). Other species showed a more narrow distribution limited to one or two stations. These limited distributions were probably related to pollution tolerance, with more opportunistic species such as *Polydora ligni* and *Corophium insidiosum* occurring with greater frequency in the inner harbor (Table 5-5). Both species are considered to be indicators of organic pollution (Anger, 1977; Wass, 1967; Rosenberg, 1976; Grassle and Grassle, 1976). Recent data, in which more careful enumerations of these small organisms were made, showed greater abundances of *P. ligni* and *C. insidiosum* at Long Wharf than Harbor Station and Fort Hale. Less tolerant species, such as *Mytilus edulis*, *Teredo navalis* and *Obelia longissima* occurred more frequently at Fort Hale and Harbor Station (Table 5-5). These species may be sensitive to either high levels of organic pollution, low dissolved oxygen, or increased temperatures (Grave, 1933; NAI, 1976; Clapp, 1937).

In general, New Haven Harbor supported a diverse fouling community with definite spatial and temporal species distributions. Species richness was generally high at Fort Hale in the outer harbor and decreased at Long Wharf in the inner harbor. Most taxa exhibited seasonal fluctuations in abundance related to spawning and settlement. Settlement on short-term panels usually occurred in July, August and September, at the height of the reproductive season. Long-term panels did not show as clear a seasonal pattern; maxima occurred in spring, summer or fall. Dominant species remained consistent in spatial distribution, with fluctuating abundances. Most displayed a seasonal pattern of abundance.

TABLE 5-4. CHARACTERISTIC TAXA DISTRIBUTIONS BY YEAR AND BY STATION (SHORT- AND LONG-TERM COMBINED). NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

YEAR	OBELIA LONGICORNIS			OBELIA SP.			METRIDIUM SENILE			SAGARTIA SP.			EUPLEURA GRACILIS			STYLOCHUS ELLIPTICUS			ETEONE HETEROPODA			EUMIDA SANGUINEA			HYDROIDES DIAPHYUS		
	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW
71	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--
72	X	X	X	--	--	--	X	X	--	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--
73	X	X	X	--	--	--	X	X	--	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--
74	X	X	X	--	--	--	X	X	--	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--
75	X	X	X	--	--	--	X	X	--	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--
76	X	X	X	--	--	--	X	X	--	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--
77	X	X	X	--	--	--	--	--	--	--	--	--	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	LEPIDORHYNCHUS SQUAMATUS			MERETIS SUCCINEA			POLYDORA SP./LIGNI			SABELLA MICROPHALMA			SERPULIDAE			CRASSOSTREA VIRGINICA			CREPIDULA FORNICATA			CREPIDULA FLAMA			MIA ARENARIA		
	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW
71	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--	X	X	X	X	X	X	X	--	--	--	--	--
72	X	X	X	X	X	X	--	--	--	X	X	--	X	X	--	X	X	X	X	X	X	X	--	--	--	--	--
73	X	X	X	X	X	X	--	--	--	X	X	--	X	X	--	X	X	X	X	X	X	X	--	--	--	--	--
74	X	X	X	X	X	X	--	--	--	X	X	--	X	X	--	X	X	X	X	X	X	X	--	--	--	--	--
75	--	--	--	X	X	X	--	--	--	X	X	--	X	X	--	X	X	X	X	X	X	X	--	--	--	--	--
76	X	X	X	X	X	X	--	--	--	X	X	--	X	X	--	X	X	X	X	X	X	X	--	--	--	--	--
77	--	--	--	X	X	X	X	X	X	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

	MYTILUS EDULIS			TEREDO NAVALIS			BALANUS EBURNEUS			BALANUS IMPROVISUS			BALANUS CREMATUS			CAPRELLIDAE			COROPHILUM INSIDIOSUM			MICROBUTORPUS GRYLLOALAPA			NEOPANOPE TEXANA		
	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW
71	--	--	--	X	X	X	X	X	X	X	X	X	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--
72	X	X	X	X	X	X	X	X	X	X	X	X	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--
73	X	X	X	X	X	X	X	X	X	X	X	X	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--
74	X	X	X	X	X	X	X	X	X	X	X	X	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--
75	X	X	X	X	X	X	X	X	X	X	X	X	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--
76	X	X	X	X	X	X	X	X	X	X	X	X	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--
77	X	X	X	X	X	X	X	X	X	X	X	X	--	--	--	--	--	--	X	X	X	--	--	--	--	--	--

	RHIZORHINOPEUS HARESI			BOHEBANKIA GRACILIS			ELECTRA CRUSTULENTA			BOTRYLLUS SCHLOSSERI			MOLGULA CITRINA			MOLGULA MANHATTENSIS			MOLGULA SPP.			PANOPEUS HERBERTII			MUDHORN TUBES		
	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW
71	--	--	--	X	--	--	X	X	X	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--
72	--	--	--	X	--	--	X	X	X	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--
73	--	--	--	X	--	--	X	X	X	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--
74	--	--	--	X	--	--	X	X	X	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--
75	--	--	--	X	--	--	X	X	X	--	--	--	X	X	X	--	--	--	--	--	--	--	--	--	--	--	--
76	X	X	X	X	X	X	X	X	X	X	X	X	--	--	--	X	X	X	X	X	X	X	X	X	X	X	X
77	X	X	X	X	X	X	X	X	X	X	X	X	--	--	--	X	X	X	X	X	X	X	X	X	X	X	X

X = present
-- = absent

TABLE 5-5. PERCENT OCCURRENCE OF ALL TAXA ON LONG-TERM PANELS AT EACH STATION, AUGUST 1971 THROUGH OCTOBER 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

FORT HALE		HARBOR STATION		LONG WHARF	
SPECIES	PERCENT OCCURRENCE	SPECIES	PERCENT OCCURRENCE	SPECIES	PERCENT OCCURRENCE
<i>Nereis succinea</i>	87.0	<i>Balanus eburneus</i>	69.6	<i>Balanus eburneus</i>	96.1
<i>Balanus eburneus</i>	75.3	<i>Nereis succinea</i>	67.5	<i>Nereis succinea</i>	74.0
<i>Teredo navalis</i>	64.9	<i>Crepidula fornicata</i>	62.3	<i>Corophium insidiosum</i>	62.3
<i>Mytilus edulis</i>	63.6	<i>Teredo navalis</i>	62.3	<i>Stylocheus ellipticus</i>	46.8
<i>Obelia longissima</i>	54.5	<i>Obelia longissima</i>	58.4	<i>Obelia longissima</i>	45.5
<i>Electra crustulenta</i>	42.9	<i>Crepidula plana</i>	58.4	<i>Teredo navalis</i>	32.5
<i>Balanus improvisus</i>	33.8	<i>Stylocheus ellipticus</i>	48.1	<i>Balanus improvisus</i>	32.5
<i>Corophium insidiosum</i>	32.5	<i>Corophium insidiosum</i>	45.5	<i>Crepidula plana</i>	31.2
<i>Stylocheus ellipticus</i>	29.9	<i>Molgula citrina</i>	40.3	<i>Mytilus edulis</i>	25.9
<i>Crepidula fornicata</i>	27.3	<i>Sabella microphthalma</i>	38.9	<i>Polydora ligni</i>	22.1
<i>Serpulidae</i>	24.7	<i>Mytilus edulis</i>	35.1	<i>Mudworm tubes</i>	20.8
<i>Metridium senile</i>	23.4	<i>Electra crustulenta</i>	31.2	<i>Electra crustulenta</i>	18.2
<i>Panopeus herbstii</i>	22.1	<i>Metridium senile</i>	29.9	<i>Sabella microphthalma</i>	15.6
<i>Obelia sp.</i>	20.1	<i>Botryllus schlosseri</i>	28.6	<i>Obelia sp.</i>	11.7
<i>Sabella microphthalma</i>	19.5	<i>Molgula manhattensis</i>	24.7	<i>Euplana gracilis</i>	10.4
<i>Crassostrea virginica</i>	19.5	<i>Serpulidae</i>	23.4	<i>Crassostrea virginica</i>	9.1
<i>Crepidula plana</i>	18.2	<i>Balanus improvisus</i>	22.1	<i>Nereis arenaceodonta</i>	9.1
<i>Mudworm tubes</i>	12.9	<i>Molgula spp.</i>	20.8	<i>Rhithropanopeus harrissi</i>	7.8
<i>Balanus crenatus</i>	12.9	<i>Obelia sp.</i>	19.5	<i>Bowerbankia gracilis</i>	7.8
<i>Balanus spp.</i>	11.7	<i>Crassostrea virginica</i>	18.2	<i>Molgula citrina</i>	7.8
<i>Sagartia sp.</i>	10.4	<i>Rhithropanopeus harrissi</i>	18.2	<i>Lepidonotus squamatus</i>	7.8
<i>Bowerbankia gracilis</i>	10.4	<i>Polydora ligni</i>	16.9	<i>Mya arenaria</i>	6.5
<i>Schizoporella unicornis</i>	9.1	<i>Panopeus herbstii</i>	15.6	<i>Balanus sp.</i>	6.5
<i>Molgula citrina</i>	9.1	<i>Balanus crenatus</i>	14.3	<i>Unidentified hydrozoan</i>	6.5
<i>Caprellidae</i>	9.1	<i>Mudworm tubes</i>	14.3	<i>Metridium senile</i>	5.2
<i>Hydroides dianthus</i>	7.8	<i>Serpulid tubes</i>	14.3	<i>Podarke obscura</i>	5.2
<i>Hydroides sp.</i>	7.8	<i>Hydroides dianthus</i>	12.9	<i>Molgula manhattensis</i>	5.2
<i>Crassostrea sp.</i>	7.8	<i>Eumida sanguinea</i>	11.7	<i>Molgula spp.</i>	5.2
<i>Gammaridae</i>	7.8	<i>Lepidonotus squamatus</i>	11.7		
<i>Molgula spp.</i>	7.8	<i>Bowerbankia gracilis</i>	11.7		
<i>Botryllus schlosseri</i>	6.5	<i>Balanus spp.</i>	10.4		
<i>Neopanope texana</i>	6.4	<i>Podarke obscura</i>	9.1		
<i>Mya arenaria</i>	6.5	<i>Microdeutopus gryllotalpa</i>	9.1		
<i>Actinaria sp.</i>	5.2	<i>Actinaria sp.</i>	7.8		
<i>Nereis arenaceodonta</i>	5.2	<i>Unidentified hydrozoan</i>	6.5		
<i>Sabellidae</i>	5.2	<i>Hydroides spp.</i>	6.5		
		<i>Unidentified decapoda</i>	6.5		
		<i>Neopanope texana</i>	6.4		
		<i>Eteone heteropoda</i>	5.2		
		<i>Euplana gracilis</i>	5.1		
		<i>Nereis arenaceodonta</i>	5.2		
		<i>Syllidae</i>	5.2		

ALL STATIONS COMBINED			
SPECIES	PERCENT OCCURRENCE	SPECIES	PERCENT OCCURRENCE
<i>Balanus eburneus</i>	87.0	<i>Caprellidae</i>	5.2
<i>Nereis succinea</i>	75.3	<i>Gammaridae</i>	5.2
<i>Obelia longissima</i>	52.8	<i>Melita nitida</i>	5.2
<i>Teredo insidiosum</i>	52.4	<i>Sagartia sp.</i>	4.8
<i>Corophium insidiosum</i>	45.9	<i>Euplana gracilis</i>	4.8
<i>Stylocheus ellipticus</i>	41.6	<i>Hydroides spp.</i>	4.8
<i>Mytilus edulis</i>	40.3	<i>Serpulid tubes</i>	4.8
<i>Crepidula fornicata</i>	38.5	<i>Mya arenaria</i>	4.8
<i>Crepidula plana</i>	35.9	<i>Microdeutopus gryllotalpa</i>	4.8
<i>Electra crustulenta</i>	29.9	<i>Eteone heteropoda</i>	3.5
<i>Balanus improvisus</i>	28.1	<i>Crassostrea spp.</i>	3.5
<i>Sabella microphthalma</i>	23.4	<i>Schizoporella unicornis</i>	3.5
<i>Metridium senile</i>	19.5	<i>Teredinidae</i>	3.4
<i>Molgula citrina</i>	19.0	<i>Sabellidae</i>	3.0
<i>Obelia spp.</i>	17.3	<i>Syllidae</i>	3.0
<i>Serpulidae</i>	16.5	<i>Unidentified decapoda</i>	2.6
<i>Crassostrea virginica</i>	15.6	<i>Jassa falcata</i>	2.2
<i>Mudworm tubes</i>	15.2	<i>Enteromorpha</i>	1.7
<i>Polydora ligni</i>	13.9	<i>Campanularia spp.</i>	1.7
<i>Panopeus herbstii</i>	13.4	<i>Diadumene leucolela</i>	1.7
<i>Botryllus schlosseri</i>	12.6	<i>Unidentified anthozoan</i>	1.7
<i>Molgula spp.</i>	11.3	<i>Phyllococe sp.</i>	1.7
<i>Molgula manhattensis</i>	10.8	<i>Ampithoe valida</i>	1.7
<i>Bowerbankia gracilis</i>	10.0	<i>Phyllococeidae</i>	1.3
<i>Rhithropanopeus harrissi</i>	10.0	<i>Potamilla neglecta</i>	1.3
<i>Balanus spp.</i>	9.5	<i>Spionidae</i>	1.3
<i>Balanus crenatus</i>	9.1	<i>Crepidula spp.</i>	1.3
<i>Hydroides dianthus</i>	7.8	<i>Caprella penantis</i>	1.3
<i>Lepidonotus squamatus</i>	6.5	<i>Microdeutopus anomalous</i>	1.3
<i>Podarke obscura</i>	6.1	<i>Unidentified amphipod</i>	1.3
<i>Nereis arenaceodonta</i>	6.1	<i>Halichondria bowerbankia</i>	1.1
<i>Actinaria sp.</i>	5.6	<i>Unidentified porifera</i>	1.1
<i>Neopanope texana</i>	5.6	<i>Halecium sp.</i>	1.1
<i>Unidentified hydrozoan</i>	5.2	<i>Sagartidae</i>	1.1
<i>Eumida sanguinea</i>	5.2	<i>Eteone sp.</i>	1.1
<i>Polydora spp.</i>	5.2		

Characteristic Taxa

Of the species considered to be characteristic, seven were characterized by high frequency of occurrence ($\geq 19\%$ overall) (Table 5-5) but generally low density. These taxa include *Nereis succinea*, *Styllocheus ellipticus*, *Crepidula* spp., *Electra crustulenta*, *Sabella microphthalma*, *Metridium senile*, and *Molgula* spp. Each will be briefly discussed with reference to percent occurrence and short-term panel settlement.

Dominant taxa, characterized by high numerical abundance as well as high frequency of occurrence, are treated in more detail. Included as dominants are *Balanus* spp., *Obelia longissima*, *Polydora ligni*, *Corophium insidiosum*, *Teredo navalis*, and *Mytilus edulis*. *Crassostrea virginica* is also discussed because of its economic importance in the harbor. The discussion for each relates life-history and thermal tolerances to seasonal and spatial distributions, including occurrence in New Haven Harbor and greater Long Island Sound. Figures 5-6 through 5-14 depict spatial/temporal distributions and abundances. The latter are converted from absolute numbers of individuals or percent coverage to 1, 2, 3 or 4 for consistency in presentation (see key, Figure 5-7). For *Balanus*, all the different taxonomic levels encountered in the study period are presented. *Balanus* spp. was used in 1975 and 1976 only. *B. crenatus* occurred only in 1974.

Selected Taxa

Nereis succinea ranked second in percent occurrence (75% overall) and was consistently present at all stations (Tables 5-4, 5-5). Numbers were seldom great but this motile polychaete was a consistent component of the harbor fouling panel community. It occurred from July through October on short-term panels (Figure 5-3).

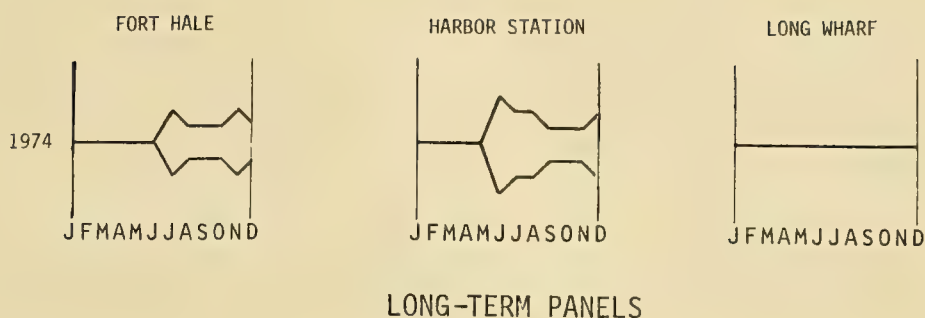


Figure 5-6. Abundance* of *Balanus crenatus* by year and by station, for years present, August 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

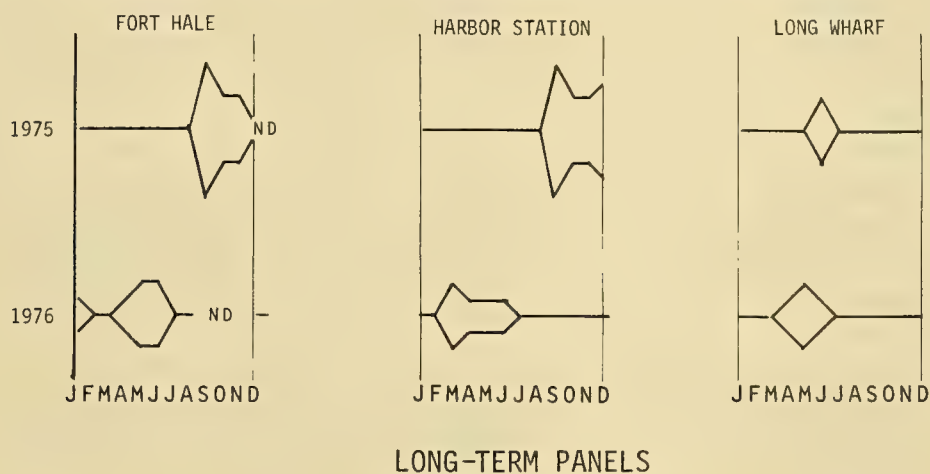
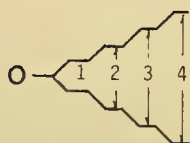


Figure 5-7. Abundance* of *Balanus* spp. by year and by station, for years present, August 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

LEGEND



INDEX	PERCENT COVERAGE	# INDIVIDUALS
0	= NO COVERAGE	= 0 COUNT
1	= <25% COVERAGE	= 1-100 COUNT
2	= 26-50% COVERAGE	= 101-500 COUNT
3	= 51-75% COVERAGE	= 501-1000 COUNT
4	= 76-100% COVERAGE	= >1000 COUNT

ND = NO DATA

MUDWORM TUBES
(WHERE FOUND)

Key for Figures 5-6 through 5-13.

*
percent coverage

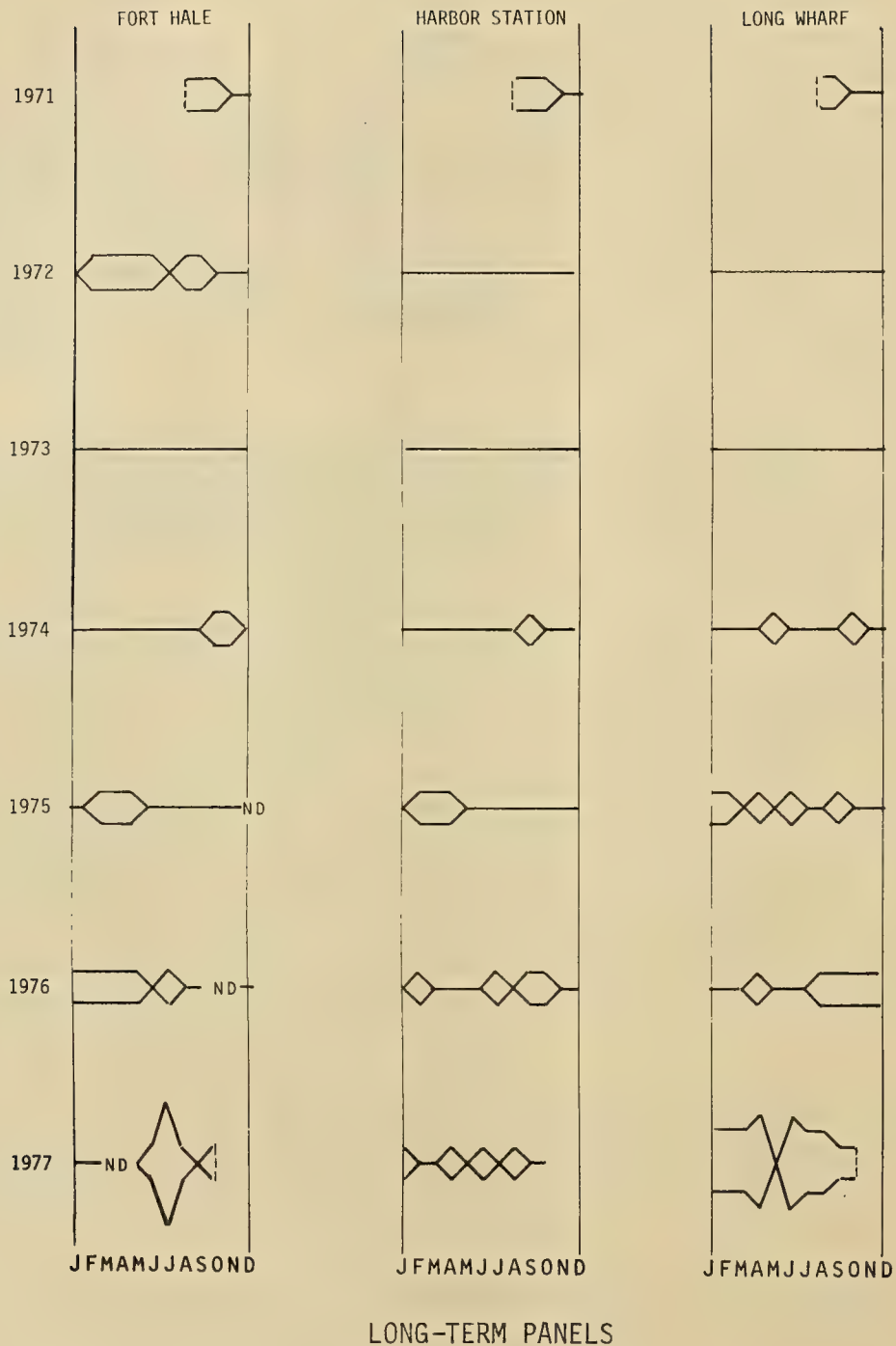
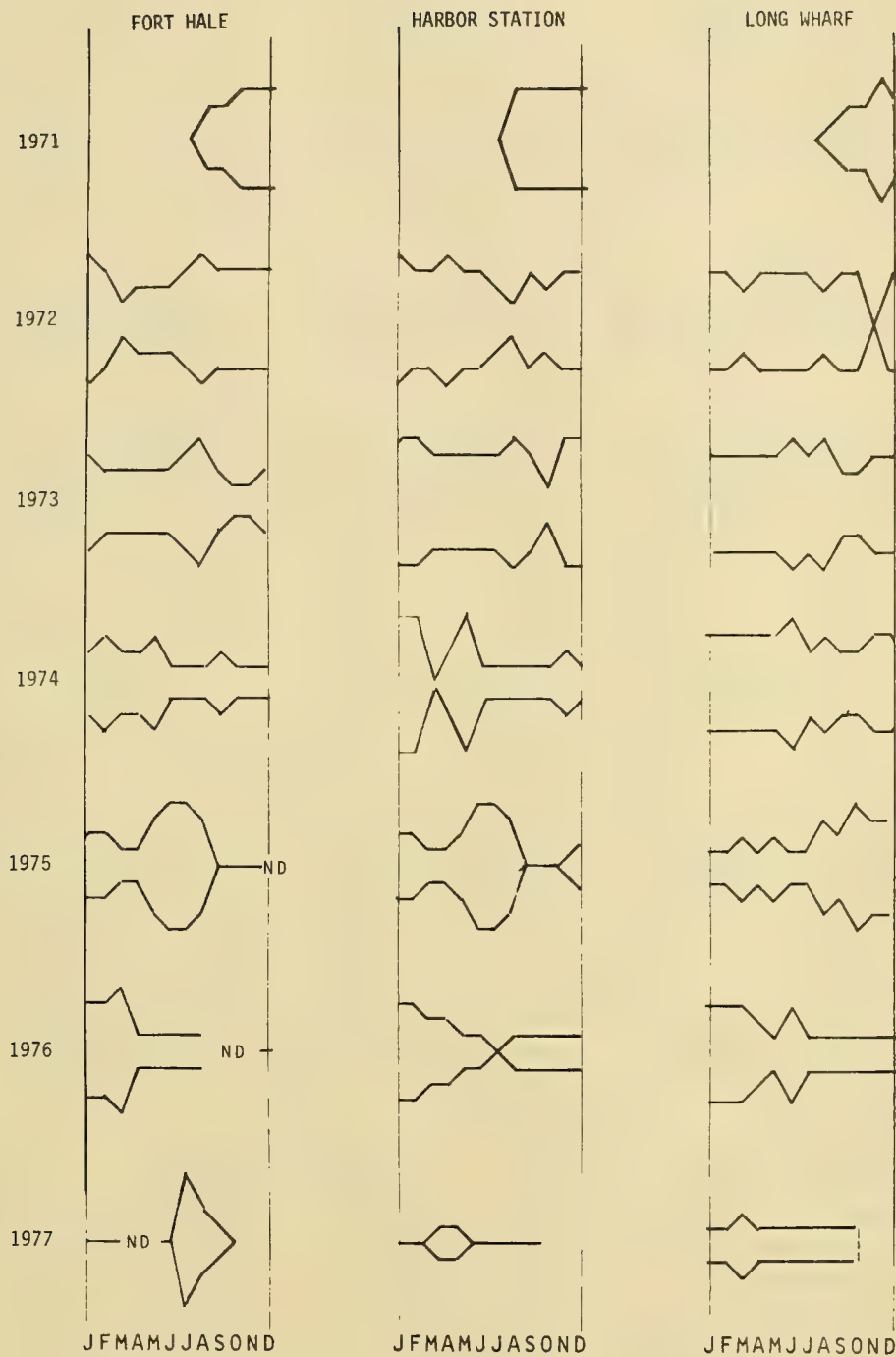


Figure 5-8. Abundance*of *Balanus improvisus* by year and by station, August 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

* $\frac{0}{10}$ coverage until July 1976, individuals/panel thereafter.



LONG-TERM PANELS

Figure 5-9. Abundance*of *Balanus eburneus* by year and by station, August 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

*

% coverage until July 1976, individuals/panel thereafter.

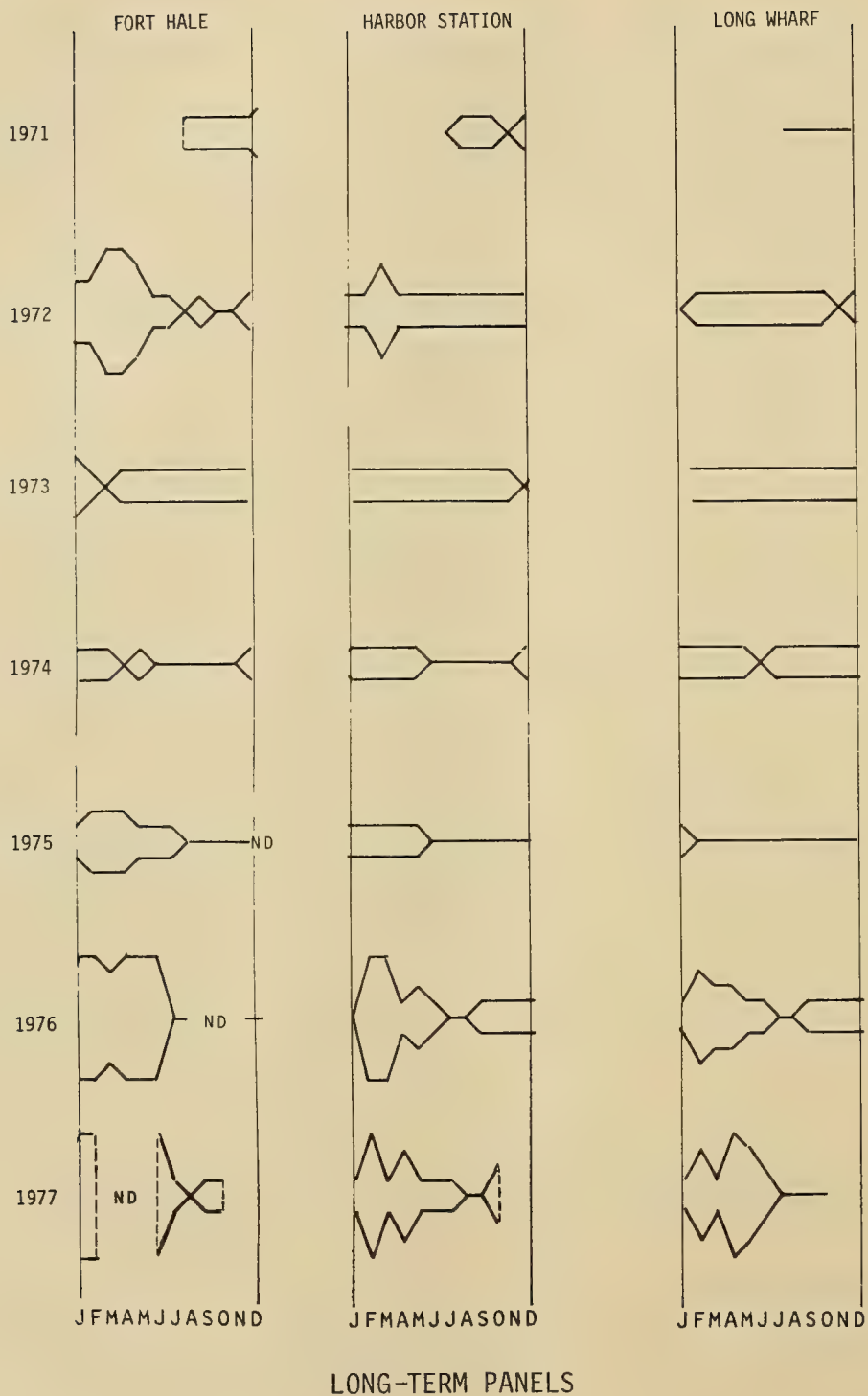
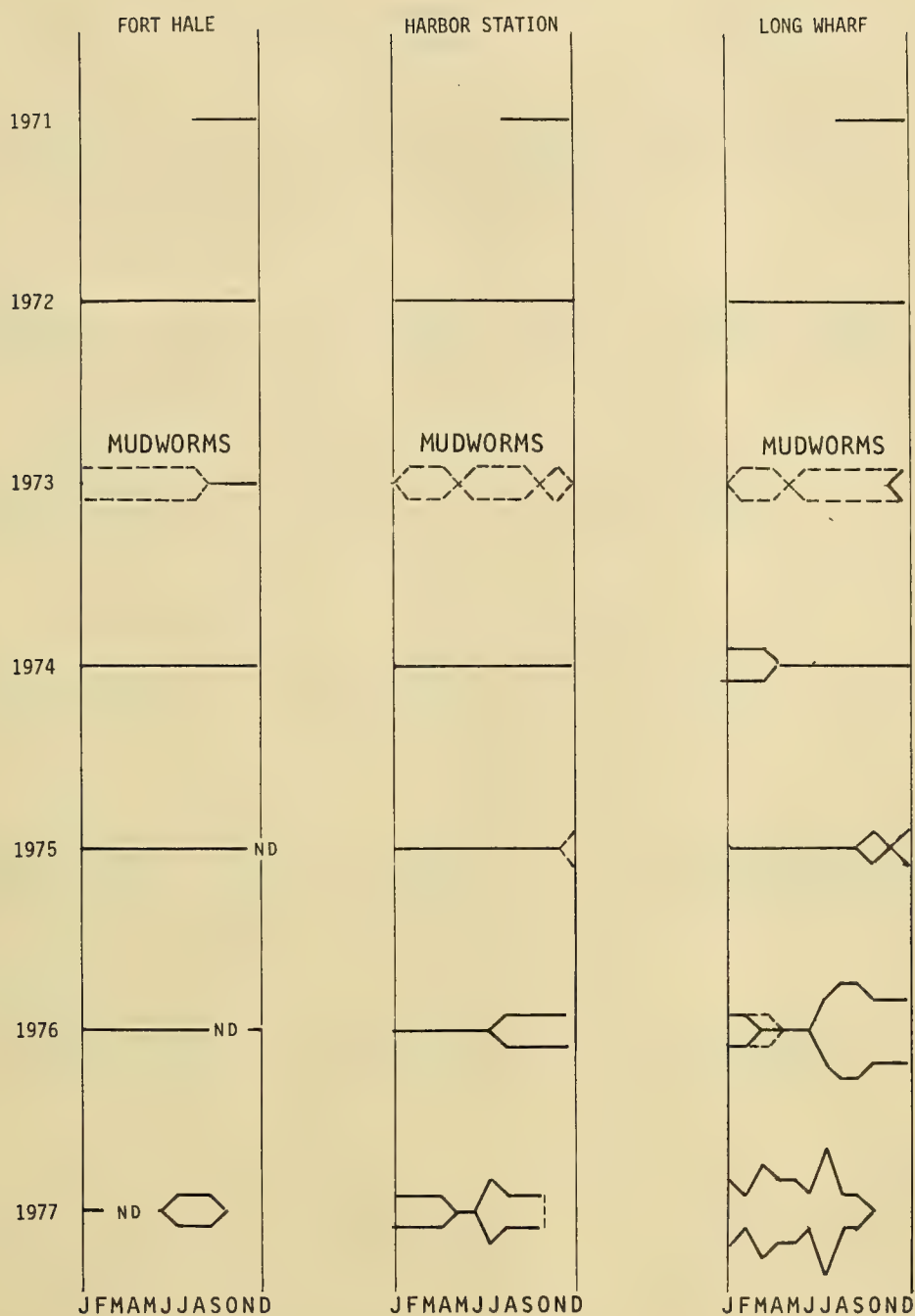


Figure 5-10. Abundance* of *Obelia longissima* by year and by station, August 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

* % coverage

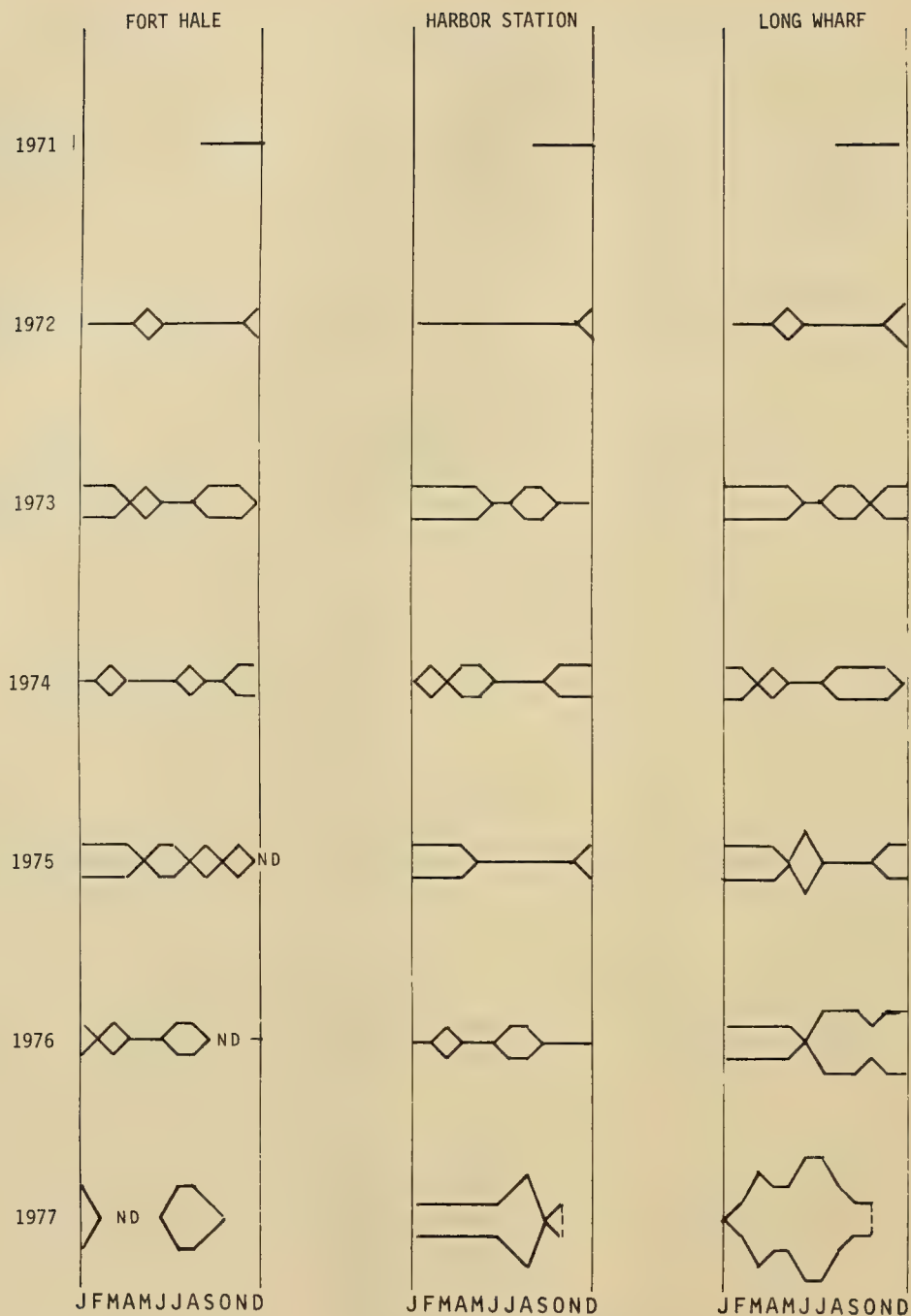


LONG-TERM PANELS

Figure 5-11. Abundance* of *Polydora* spp./mudworm tubes by year and by station, August 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

*

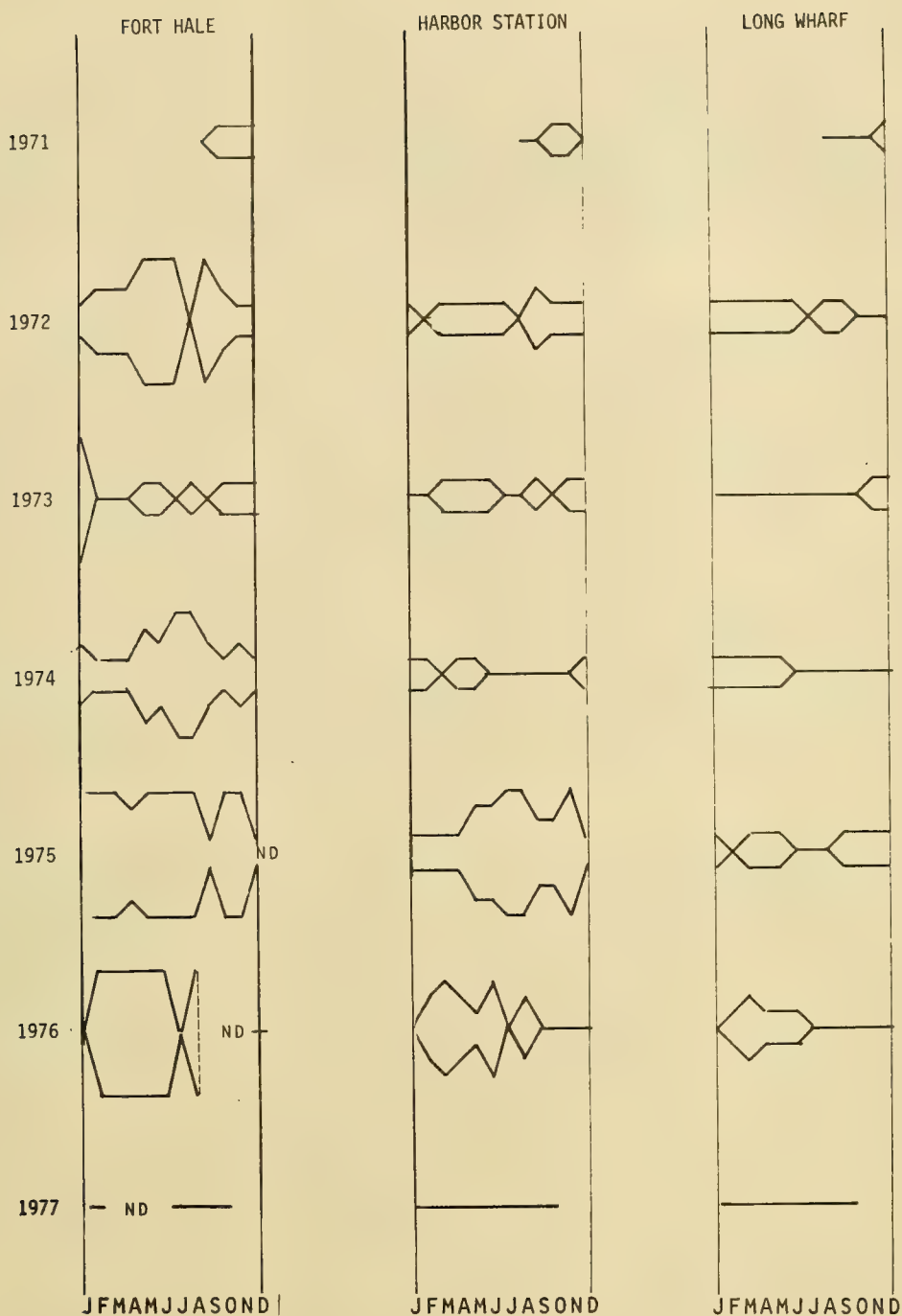
individuals/panel



LONG-TERM PANELS

Figure 5-12. Abundance* of *Corophium insidiosum* by year and by station, August 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

* individuals/panel



LONG-TERM PANELS

Figure 5-13. Abundance*of *Teredo navalis* by year and by station, August 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

* coverage until January 1976, individuals/panel thereafter.

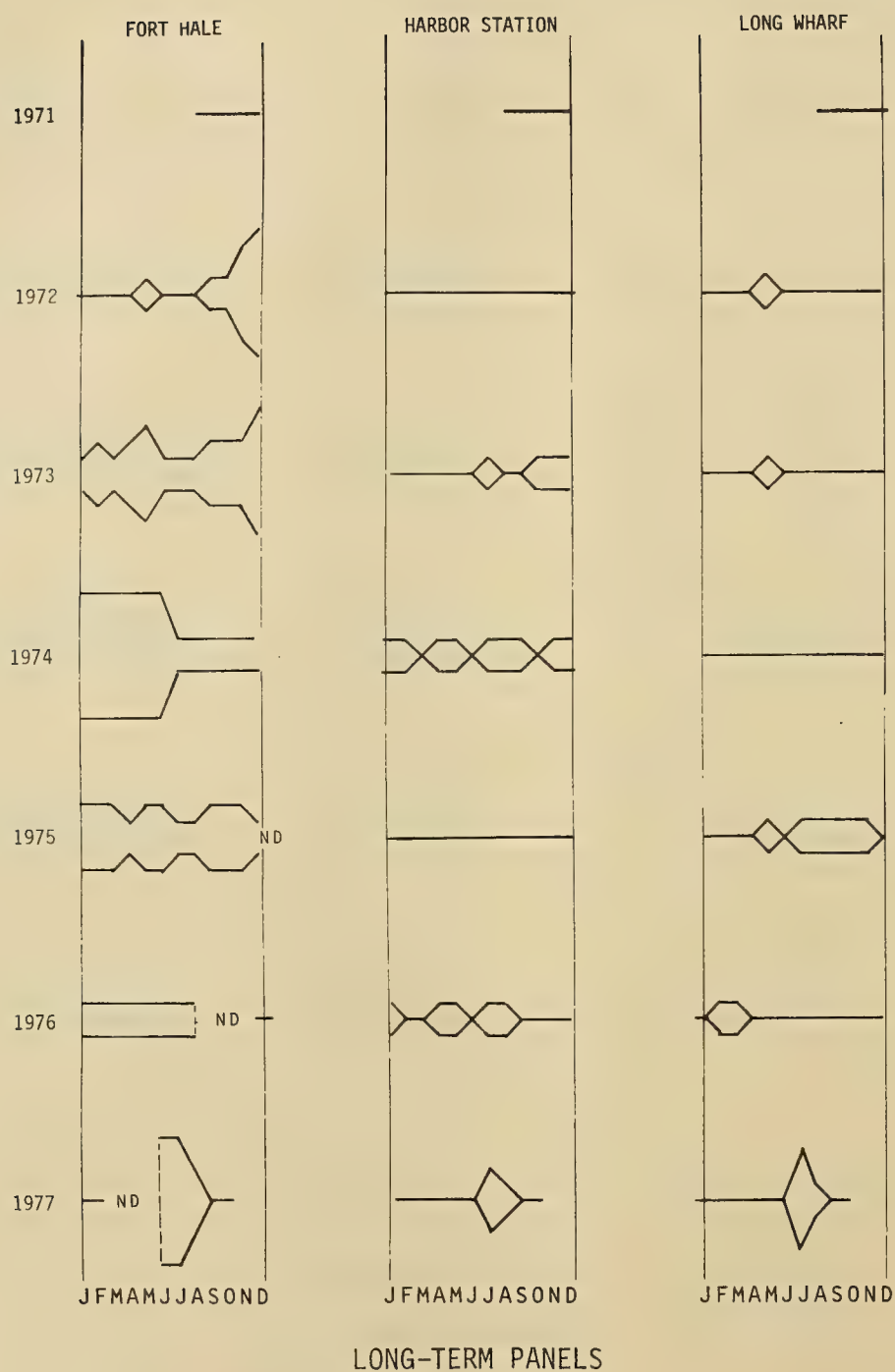


Figure 5-14. Abundance*of *Mytilus edulis* by year and by station, August 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

* % coverage until January 1975, individuals/panel thereafter

Styllocheus ellipticus, a turbellarian, ranked 42% overall, and was consistently present at all stations in low numbers (Tables 5-4, 5-5). This motile species preys mainly on barnacles (Osman, 1977). Its presence on short-term panels was observed from June through October (Figure 5-3). Osman (1977) noted settlement from late June through October in the Woods Hole region.

Crepidula fornicata and *C. plana*, slipper shells, showed percent occurrences of 38% and 36% respectively and occurred at all stations for most years (Tables 5-4, 5-5). *C. plana* was consistently found on short-term panels in July and August (Figure 5-3).

Electra crustulenta, an ectoproct, showed an overall percent occurrence of 30% with presence at all stations for most years (Table 5-5). Occurrence on short-term panels was noted from August through October (Figure 5-3). Hoagland et al. (1977) noted fall settlement of this species in a New Jersey estuary.

Sabella microphthalma, a tube-dwelling polychaete, had a percent occurrence of 23% overall in the assemblage (Table 5-5). Osman (1977) noted that this species was able to extend its tube linearly and keep the open feeding end ahead of overgrowing species. He suggested that overgrowth of other taxa against the base of their tubes may add an additional layer of protection. Settlement was observed from July through October in New Haven Harbor. Osman (1977) noted settlement from July through August at Woods Hole (Figure 5-3).

Metridium senile, an anemone, had a 20% occurrence overall and was most common at Fort Hale and Harbor Station (Table 5-5). Its upright growth pattern, allows it to feed and spawn above the majority of other settling species, enabling it to exist on crowded panels (Osman, 1977).

Molgula citrina and *Molgula* spp. showed 19% and 11% occurrence overall respectively with most consistent occurrence at Harbor Station

(Table 5-5). This solitary tunicate can form fairly extensive assemblages on crowded panels because of its small basal area and upright growth form (Osman, 1977). Osman observed that *Molgula* spp. dominated entire panels in the Woods Hole region. Settlement on short-term panels occurred from July through October in New Haven Harbor (Figure 5-3), and from May through October at Woods Hole (Osmann, 1977). Hoagland *et al.* (1977) observed settlement of *M. manhattensis* throughout the fall in New Jersey.

Dominant Taxa

Balanus spp.

Balanus eburneus, *B. improvisus* and *B. crenatus* were present during some sampling periods on New Haven Harbor panels from 1971 through 1977 (Figures 5-6, 5-8, 5-9). *Balanus* spp., which consisted mostly of difficult-to-identify juveniles, was recorded from 1975 to 1976 (Figure 5-7). *B. improvisus* and *B. eburneus* were codominants in New Haven Harbor with *B. eburneus* more abundant prior to 1976 and *B. improvisus* more abundant thereafter. *B. crenatus* was abundant only in 1974. *B. eburneus* and *B. improvisus* occurred at all sites, while *B. crenatus* never occurred at Long Wharf.

The three barnacle species have similar life history patterns. Though hermaphroditic, barnacles usually cross-fertilize. Adults brood the eggs in the mantle cavity and the nauplius larvae hatch as plankton. Cypris larvae are the mature planktonic stage which subsequently settle and metamorphose into adults. Barnacles are gregarious and preferably set with other barnacles but in general any hard substrate will suffice. There are a host of factors including texture, angle, and current rate which influence barnacle settlement (Crisp and Barnes, 1954, Crisp and Stubbings, 1957). *Balanus improvisus* has been reported to settle in greater numbers in low salinity estuaries (NAI, 1977c).

Settlement of barnacle spat was similar in 1977 at New Haven Harbor to previous years. Observations on settlement are not complete for each species because barnacle spat are difficult to identify. In 1977, settlement of *Balanus* spp. on short-term panels was first observed in April with a second, more intense set occurring in June through October, and peaks in June, July and September (variable). *Balanus improvisus* was identified in the April set and comprised one-half of the July set. *B. eburneus* was positively identified only in mid-June, but as the majority of the juveniles in June and September were unidentified it is likely that there were more *B. eburneus* than indicated. Grave (1933) observed *B. eburneus* setting at Woods Hole in mid-June through July with a small September set.

The apparent recent increase in *Balanus improvisus* beginning in 1975 probably reflects a series of more successful spawnings for the species in New Haven Harbor but it may be related to improved identification of juvenile forms from *Balanus* spp. to *Balanus improvisus*. *B. improvisus* occurred in slightly greater numbers at Long Wharf than the other stations but did not show a substantially greater percent occurrence at this lower salinity station. Hydrographic data for New Haven Harbor do not indicate any temperature changes that could be the basis for species composition shifts. The shift to *Balanus improvisus* does not appear to be a Long Island Sound phenomenon because data from Millstone 1976 and 1977 indicate high numbers of *B. eburneus* (Battelle, 1977, 1978). Millstone data for 1973 showed only *B. eburneus* and *B. crenatus* on long-term panels although *B. crenatus* was excluded at the effluent station (Battelle, 1977). Short-term panels at Millstone showed *B. eburneus* settling in July, August and September and *B. improvisus* in August; no *Balanus crenatus* were seen on 1973 short-term panels. In New Jersey, *B. eburneus* was reported to set throughout the summer and into September; larvae of *B. improvisus* and *B. crenatus* began settling after September (Hoagland et al., 1978). Fall population reductions of *B. eburneus* (Figure 5-9) seen most years at all stations in New Haven Harbor corresponds to observations of high mortality rates of balanoids in September and October (Fuller, 1946, in TRIGOM, 1973).

Obelia longissima

Distribution and seasonal abundance patterns of *O. longissima* remained consistent at New Haven harbor over the period studied. Maximum coverage was reported from late winter through spring with peaks in February, March and April. "Die-off" of colonies at all sites with increasing temperatures usually occurred after May/June (Figure 5-10). The short-term, month-to-month variability observed was probably a function of colony growth rate. During spring settlement, the number of polyps in a growing colony doubles every 2-3 days, allowing for rapid colonization of substrate (Grave, 1933). The colony consists of hundreds of thousands of individuals before it becomes sexually mature. The normal longevity of a colony is less than one year (Grave, 1933).

Seasonal abundance patterns of *Obelia* were consistent in New Haven Harbor and followed patterns similar to those observed in the Woods Hole region. At Long Wharf and Harbor Station, the inner harbor sites, numbers were slightly lower than at Fort Hale in the outer harbor. Grave (1933) described lower *Obelia* densities in areas subject to higher levels of suspended matter at Woods Hole. He postulated that the reduction in growth was related to contamination of *Obelia* by bacterial populations associated with the suspended matter. In New Haven higher levels of suspended matter generally occur in the inner harbor (NAI, 1978), possibly accounting for the lower Long Wharf and Harbor Station densities. Degeneration of colonies at all sites when temperatures increased after May/June was observed in New Haven Harbor (Figure 5-10) and by Grave (1933) in Woods Hole. Subsequent new growth occurred in September at Woods Hole from vegetative remains of spring populations. At Niantic Bay, *Obelia* occurred throughout 1973 with lower densities in August. *Obelia* settled on short-term panels at Niantic primarily in June (Battelle, 1974).

Polydora ligni

Polydora ligni is a small, tube-dwelling spionid polychaete commonly found on oyster and mussel beds. It was extremely abundant from July 1976 through 1977 on panels maintained at Long Wharf and occurred in lower numbers throughout New Haven Harbor.

Work on pollution-indicator species revealed this opportunistic (Grassle and Grassle, 1974) mudworm to be an indicator of organic pollution (Anger, 1977; Leppäkoski, 1975). It is restricted to estuaries (Blake, 1969) where it builds tubes of silt from suspended sediments (TRIGOM, 1973). Reproduction occurs early in the spring (TRIGOM, 1973), after which adults brood their eggs in tubes and the larvae are released to the water column from April through July (Blake, 1969). *P. ligni* are gregarious with larvae tending to settle near other mudworm tubes. Larsen (in TRIGOM, 1973) reported peak densities of $10,721/\text{m}^2$ as a normal post-reproductive level. These high densities can cause extensive silt build-up resulting in oyster mortality (Daro and Polk, 1973; Galtsoff, 1964).

Distribution of *Polydora ligni* in New Haven Harbor and other Long Island Sound estuaries has been sporadic. Unusually high numbers recorded in New Haven Harbor at Long Wharf in 1976 and 1977 may have been the result of a successful population set (Figure 5-11); alternatively, previous years' samplings may have underestimated this species, when it was recorded in lower numbers as mudworm tubes. The generally higher abundance at Long Wharf is probably related to the higher silt content of the inner harbor. Seasonal peak abundances were reported in July at Long Wharf in 1976 and all stations in 1977. Mudworm tubes at Millstone were recorded in August and September 1973 on short-term panels.

Corophium insidiosum

Corophium insidiosum, a tube-dwelling amphipod, increased in abundance throughout the study, with maximum numbers at Long Wharf.

Corophium insidiosum has been classed as an opportunistic species and an indicator of slight organic pollution (Anger, 1977). *C. insidiosum* spawns within its burrows from February through April, the females retaining the larvae in their brood pouch. Females may have 4-5 broods per year, the offspring of which reproduce in the same season. Densities may reach 63,000/m² (TRIGOM, 1973). *C. insidiosum* is a commensal of *P. ligni*, utilizing the polychaete tubes to provide suitable habitat as well as feeding on microorganisms living in the tubes (Daro and Polk, 1973). The similarity in distribution between *C. insidiosum* and *P. ligni* has been documented in a number of areas: Maine (Fuller, 1946), Chesapeake Bay (Cory, 1967), California (Graham and Gay, 1945), North Sea (Daro, 1970), and the Baltic Sea (Anger, 1977).

Corophium insidiosum distribution patterns in New Haven Harbor were similar to other areas. Percent occurrence values of 62, 46 and 33 percent at Long Wharf, Harbor Station and Fort Hale, respectively, in conjunction with Figure 5-12, indicate maximum numbers and occurrence at Long Wharf, a silty, inner-harbor station. Highest abundances, exceeding 250,000/m², in 1977 were reported during July and August following juvenile settlement (NAI, 1978a). The 1976 abundance peak was also during the summer, but 1974, 1973 and 1972 showed spring maxima with smaller numbers settling in the fall. Studies at the Piscataqua River, New Hampshire showed *C. insidiosum* settling mainly in the spring and summer (NAI, 1977c). *C. insidiosum* at Niantic Bay settled primarily in August (1973) on short-term panels and showed highest long-term panel densities in July; it was present in high numbers all months of 1973 except May (Battelle, 1978).

Teredo navalis

Teredo navalis, the shipworm, is common on the east coast in temperate waters (Turner, 1966). It was an abundant species in New Haven Harbor prior to its sudden absence from the panels beginning in September 1976. Recent data (July 1978) from subsequent studies in New Haven Harbor indicate a return to previous densities (NAI, in preparation). Figure 5-13 shows a decreasing abundance gradient from Fort Hale to Long Wharf, which may be related to poorer water quality in the inner harbor.

Success and cosmopolitan distribution are attributable to the habit of brooding young, and the wide salinity and temperature tolerance of *T. navalis* (R. Turner, 1966). Roch (in Clapp, 1937) reported considerable tolerance to low dissolved oxygen and salinity and attributed this to the ability of *T. navalis* to seal off its burrow in an incompatible medium; it was observed to withdraw for up to 33 days in poor conditions. Boring activity decreased in low-salinity water, silty conditions, or temperatures less than 5°C or greater than 25°C (Roch, in Clapp, 1937). *T. navalis* normally spawns at temperatures between 17.5 and 30°C and retains the embryos in burrows, releasing larvae from 13 to 30°C (Culliney, 1975).

Distributions of *T. navalis* in New Haven Harbor and greater Long Island Sound were consistent with literature reports. Percent occurrence values were 65, 62 and 32 percent at Fort Hale, Harbor Station and Long Wharf, respectively (Table 5-5). Figure 5-13 indicates early summer maxima at all stations with decreases in August and subsequent increases in the fall. Data from Niantic Bay (Battelle, 1974) showed consistent monthly infestation with a maximum in July followed by an August decline. Short-term panels in New Haven Harbor showed September and October settling in 1971, 1973, 1974, 1975 (Figure 5-3). Niantic Bay data for 1973 indicated August and (primarily) September settlement. *Teredo* settled at a similar time in a New Jersey estuary (Hoagland, et al., 1977). After August 1976 in New Haven Harbor, *T.*

navalis disappeared at all stations. The reason for its disappearance is not clear, but other studies have recorded wide fluctuations in the *Teredo* abundance pattern in the Long Island Sound area (Clapp, 1937).

Mytilus edulis

Mytilus edulis, the common blue mussel, is widely distributed around the world in temperate waters (TRIGOM, 1973). Distribution at New Haven Harbor showed abundances decreasing from outer to inner harbor stations for all years (Figure 5-14).

Mytilus is considered to be fairly tolerant of organic pollution (Anger, 1976), but is sensitive to high summer temperatures. The optimum temperature for the species is between 5-20°C (TRIGOM, 1973) (sometimes exceeded by late summer temperatures in New Haven Harbor), and it has an absolute upper lethal temperature of 30°C (Van Winkle, 1973 in NAI, 1977b). The adult mussel's ventilation rate drops at temperatures in excess of 20°C (Widdows, 1973). *Mytilus* spat, however, live four times as long as adults at 28°C (Pearce, 1969). Settlement of mytilids is largely temperature dependent and does not normally begin until early summer when water temperatures exceed 13°C (WHOI, 1952).

New Haven Harbor *Mytilus* distributions were consistent with other observed mytilid distributions in Long Island Sound. Short-term panel data (Figure 5-3) indicated that settlement occurred primarily in the summer but overlapped the spring and fall of some years. Millstone Harbor panels showed that *Mytilus* settled in September (Battelle, 1974). *Mytilus* is common in Long Island Sound, occurring at Bridgeport (NAI, 1973b), Millstone, and New Haven Harbor; it is absent only at Stamford (NAI, 1973c). Within New Haven Harbor, *Mytilus* showed percent occurrences of 64, 35 and 22 percent at Fort Hale, Harbor Station and Long Wharf respectively (Table 5-5). Abundances also showed a gradient decreasing from Fort Hale to Long Wharf (Figure 5-14), probably related to poorer water quality in the inner harbor.

Crassostrea virginica

New Haven Harbor serves as a primary natural source of oyster seed for Long Island Sound (NAI, 1978a). Oysters showed greater numbers on exposure panels at Fort Hale and Harbor Station and occurred during all years at these stations. Presence on short-term panels was limited to August and September (Figure 5-3).

C. virginica has been recorded in sheltered, shallow subtidal, and intertidal marine and estuarine water (TRIGOM, 1973) with temperatures ranging seasonally from 1-32°C (Galtsoff, 1964). They are inactive at temperatures less than 8°C and mortality increases at greater than 35°C (Mackin, 1968). Reproduction occurs during the summer when temperatures exceed 20°C, usually from late June to late August in Long Island Sound (Loosanoff, 1965 in TRIGOM, 1973). The average female oyster releases over 50 million eggs per year from which about one dozen reach maturity. The planktonic larvae are quite specific in their settling requirement for other oyster shells which results in low recruitment on short-term panels.

COMPARISON OF NEW HAVEN HARBOR WITH OTHER LONG ISLAND SOUND SITES

Hillman (1973) compared the results of exposure-panel studies conducted in the Long Island Sound area in 1971-1972 at Niantic Bay and Stamford and New Haven Harbors. He observed a similarity in phyla present on panels at all sites, but noted a greater total number of species at Niantic Bay, which he attributed to better water quality. Table 5-6 lists abundant species taken from fouling panels at four sites in Long Island Sound from October 1971-September 1972. New Haven Harbor and Niantic Bay had a number of species in common: *Balanus eburneus*, *B. improvisus*, *Teredo navalis*, *Corophium insidiosum*, *Mytilus edulis*, *Nereis succinea*, and *Halichondria bowerbankia*. Of these common species, Stamford had three (*Corophium* sp., *Nereis succinea* and *Teredo navalis*) and Bridgeport had two (*Mytilus edulis* and *Nereis succinea*).

TABLE 5-6. FAUNAL SPECIES PRESENT AT SELECTED LOCATIONS IN LONG ISLAND SOUND.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

NEW HAVEN HARBOR (1935)	NEW HAVEN HARBOR (1971-72)	BRIDGEPORT HARBOR (1971)	NIANTIC BAY (1971-72)	STAMFORD HARBOR (1971-72)
Coelenterata <i>Obelia</i> sp.	<i>Obelia longissima</i> <i>Metridium senile</i>	<i>Tubularia crocea</i> Campanularidae	<i>Sertularia pumila</i>	<i>Obelia gelatinosa</i>
Porifera	<i>Halichondria bowerbankia</i>		<i>Halichondria bowerbankia</i>	
Platyhelminthes	<i>Stylocheilus ellipticus</i>	<i>Euplana gracilis</i>		
Mollusca	<i>Mytilus edulis</i> <i>Teredo navalis</i> <i>Crepidula plana</i> <i>Crassostrea virginica</i> <i>Crepidula fornicata</i>	<i>Mytilus edulis</i> <i>Mya arenaria</i> <i>Mya truncata</i>	<i>Mytilus edulis</i> <i>Teredo navalis</i>	<i>Teredo navalis</i> Teredinids
Annelida	<i>Nereis arenaceodonta</i> <i>Nereis succinea</i>	<i>Polydora ligni</i> <i>Spio</i> sp. <i>Nereis succinea</i> <i>Nereis arenaceodonta</i> <i>Nereis virens</i>	<i>Nereis succinea</i> <i>Nereis pelagica</i> Phyllodoctidae <i>Lepidonotus squamatus</i>	<i>Nereis succinea</i> <i>Nereis pelagica</i> Leptoplanidae Phyllodoctidae
Arthropoda Corophium tubes <i>Limnoria</i> sp. <i>Balanus eburneus</i>	<i>Corophium cylindricum</i> <i>Balanus eburneus</i> <i>Balanus improvisus</i> <i>Corophium cylindricum</i> <i>Melita dentata</i> <i>Jaera marina</i>	Amphipods <i>Balanus improvisus</i> <i>Anoploleptus lentus</i>	<i>Corophium cylindricum</i> <i>Limnoria tunnels</i> <i>Balanus eburneus</i> <i>Balanus improvisus</i> <i>Balanus crenatus</i> <i>Chelura terebrans</i>	<i>Corophium cylindricum</i> <i>Limnoria tripunctata</i> <i>Balanus crenatus</i> <i>Gammarus locusta</i> <i>Caprella geometrica</i> Ampithoe
Ectoprocta	<i>Bowerbankia gracilis</i> <i>Electra crustulenta</i> <i>Schizoporella unicornis</i>		<i>Bugula simplex</i> <i>Bugula turrita</i> <i>Cryptosula pallasiana</i>	<i>Electra crustulenta</i> <i>Cryptosula pallasiana</i>
Chordata <i>Molgula manhattensis</i>	<i>Molgula citrina</i>	<i>Botryllus schlosseri</i> <i>Molgula manhattensis</i>	<i>Botryllus schlosseri</i>	<i>Botryllus schlosseri</i>

Examination of 1977 biota on long-term panels in New Haven Harbor and Niantic Bay reveals a similar faunal composition (Table 5-7). As in 1971-1972, Niantic panels had a diverse flora while New Haven Harbor panels had almost no algae at all. Sites at Millstone Point (Niantic Bay) and Harbor Station show 48 and 51 faunal species respectively (Battelle, 1978; NAI, 1978). Characteristic New Haven species not occurring at Niantic (1977) were: *Molgula* sp., *Mya arenaria*, *Polydora* sp., and *Electra crustulenta*. Dominant species occurring since 1971 at Millstone were: *Obelia* sp., *Mytilus edulis*, *Nereis succinea*, *Botryllus schlosseri*, and *Crassostrea virginica*. Dominant Niantic Bay species not represented at New Haven Harbor are *Limnoria tripunctata*, *Chelura terebrans*, and *Idotea phosphorea*. Virtually all of the current Millstone faunal species were represented at New Haven Harbor; many of the algal species were not. This is also true for Stamford and Bridgeport Harbors (Table 5-6). In the 1935 study of New Haven Harbor, only dominant species were determined (Battelle, 1937). This study listed *Balanus eburneus*, *Obelia* spp., *Corophium* spp., *Molgula* spp., and *Mytilus edulis* as occurring in New Haven Harbor. Most of these are currently recorded as dominants, occurring at most stations during years of the current study. A major change observed in New Haven Harbor was the temporary disappearance of *Teredo navalis* in 1976 after a highly consistent occurrence from 1971 through August 1976. As indicated earlier, previous work in the Long Island Sound region has documented such fluctuations in the species (Clapp, 1937).

In summary, the present study shows that New Haven Harbor had high faunal species richness relative to other Long Island Sound panel study sites. Annual differences in community structure within New Haven Harbor which have been reported may be attributed to taxonomic refinements, changes in water quality, and length of sample period. In general, it is difficult to define a "typical" Long Island Sound fouling community. Panel colonization is directly dependent upon the abundance of settling larvae, which in turn is a function of seasonality, larval selectivity, and the immediate physical/chemical characteristics of the area. Changes in seasonal hydrographic parameters can affect the entire

TABLE 5-7. CHARACTERISTIC* TAXA PRESENT AT NEW HAVEN HARBOR AND MILLSTONE POINT, 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	NEW HAVEN HARBOR (1977)	NIANTIC BAY (1977)
<i>Obelia longissima</i>	X	X
<i>Metridium senile</i>	X	--
<i>Euplana gracilis</i>	X	X
<i>Stylochus ellipticus</i>	X	X
<i>Eteone heteropoda</i>	X	--
<i>Eumida sanguimida</i>	X	X
<i>Hydroides dianthus</i>	X	X
<i>Lepidonotus squamatus</i>	X	X
<i>Nereis succinea</i>	X	X
<i>Polydora ligni</i>	X	--
<i>Sabella microphthalma</i>	X	X
<i>Crassostrea virginica</i>	X	X
<i>Crepidula fornicata</i>	X	X
<i>C. plana</i>	X	X
<i>Mya arenaria</i>	X	--
<i>Mytilus edulis</i>	X	X
<i>Teredo navalis</i>	X	X
<i>Balanus eburneus</i>	X	X
<i>B. improvisus</i>	X	X
Caprellidae	X	X
<i>Corophium insidiosum</i>	X	X
<i>Microdeutopus gryllotalpa</i>	X	--
<i>Rithropanopeus harrisi</i>	X	--
<i>Bowerbankia gracilis</i>	X	--
<i>Electra crustulenta</i>	X	X
<i>Botryllus schlosseri</i>	X	X
<i>Molgula citrina</i>	X	--
<i>Molgula manhattensis</i>	X	--

X = present

-- = absent

*

present at all Stations in New Haven Harbor for at least one year and with a total rank abundance >3.5%.

composition of a community (Osman, 1977). Osman found substantial differences in community structure which were dependent upon the time of initial settlement, length of exposure, size of panel, and nature of disturbance. In New Jersey, yearly cycles in settlement were reported to be similar from year to year, but species composition was annually variable (Hoagland, 1977). There does, however, seem to be a fairly stable New Haven Harbor panel assemblage that bears some similarity to Millstone (1977) and undergoes periodic additions and deletions. Dominant members of this assemblage include: *Corophium insidiosum*, *Polydora ligni*, *Balanus eburneus*, *B. improvisus*, *Obelia longissima*, *Teredo navalis*, and *Mytilus edulis*.

ANALYSIS OF IMPACTS OF NEW HAVEN HARBOR STATION OPERATION

The possible impact of New Haven Harbor Station operation on the benthic community as studied by exposure panels would be related to operation of the condenser-cooling system. The condensers receive ambient temperature water and discharge heated effluent at 15°F above ambient (NAI, 1976b). The thermal plume (dating from operation start-up 29 August 1975) intersects the surface at a temperature of 4°F above ambient and occupies an area less than 0.1% of the inner harbor. The 3, 2 and 1°F isotherms bound 0.4, 0.6 and 1.0 percent of the inner harbor area, respectively (Section 3-2 this report). A special survey revealed that the thermal plume from the station could occasionally intersect Stations 8 and 9 with a 0.9 - 1.8°F (0.5 - 1°C) temperature increase (NAI, 1977). The New Haven Harbor Station fouling panel array (B) is adjacent to Station 9 (Figure 5-1).

Entrainment in the condenser cooling water and exposure to increased water temperatures from the thermal plume are the major modes of impact associated with power-station operation. As discussed in the introduction, entrainment may reduce numbers of recruitable larvae to the fouling panel community. Depending on their magnitude, increased water temperatures have a range of potential impacts upon the community,

including: increase or decrease in productivity, behavioral changes, shifting species composition, lengthening of spawning/settlement period, reduction in physical condition and cumulative effects resulting in death. Cory and Nauman (1969) and Nauman and Cory (1969) measured increases in panel productivity (gm dry wt/m² time) in effluent canals at two sites in the Patuxent River Estuary. Tinsman and Maurer (1974) observed greater condition indices (amount of stored glycogen) and meat weight of oysters in effluent waters. All of the above researchers noted increased productivity for some years and mortality for other years in July/August in thermal effluent canals due to temperature increases. In mussels (*Mytilus edulis*), behavior that could also result in increased loss due to predation occurred at temperatures well below lethal limits (Pearce, 1969); at 24°C, normal aggregation of *Mytilus* did not occur and the byssal fibers, while attached, did not secure the mussel firmly to the substratum. A thermal addition could result in a range extension of warmer water species or exclusion of colder-water species existing at the limits of thermal tolerance (Naylor, 1965). Prolonged breeding periods have been reported in a number of thermal addition studies (NAI, 1973b, 1977c). Pearce (1969) noted that heat added subsequent to another stress or pollution factor, often resulted in mortality at a lower critical temperature. Many of the adverse effects caused by thermal impact are reversible. Thus, Naylor (1965) noted a rapid return of a thermally-impacted community to its original composition.

The New Haven Harbor fouling community did not indicate any impact from station operation. An examination of species-richness values over the entire period revealed an increase from 1971 to 1976, followed by a decrease in 1977 at all stations as previously discussed (Figure 5-4). A change in taxonomic treatment clearly accounts for some differences; other factors are the shorter sampling period in 1977 and loss of long-term panels at Fort Hale in 1977. *Teredo's* absence from 1976 to 1978 is not considered to be related to New Haven Harbor Station operation; its disappearance was not localized at Harbor Station and it was recorded in high numbers in recent (1978) data. None of the domi-

nant species showed changes in distribution or abundance that could be related to station operation. Three previously unrecorded species at Harbor Station and other stations were found in 1976: *Rithropanopeus arrissi*, *Eteone heteropoda* and *Euplana gracilis*. Numerous other species have been variable in occurrence (Table 5-8).

The study conducted at Bridgeport Harbor 1971-1972 (NAI, 1973) did not discern any effect of thermal effluent on faunal composition. The difference between control and effluent station temperatures was 11°C (March-August 1971). The most obvious effect was the month-earlier settlement of most species in the effluent. Species present are listed in Table 5-6. Faunal diversity was greater at the discharge than the control; this is the opposite of the result at the Piscataqua River estuary in New Hampshire and Millstone Harbor where the immediate discharge area was lower in diversity (NAI, 1977a; Battelle, 1977). In addition, at Millstone, a subtropical species, *Teredo bartschii*, has occurred regularly in the effluent since 1975.

Careful examination of potential modes of electrical generating plant impact indicate that there has been no measurable effect on New Haven Harbor Station fouling communities.

SUMMARY

A total of 75 species and numerous higher taxa were identified from New Haven Harbor exposure panels during the sampling period August 1971-October 1977 (Table 5-8). The dominant species were the barnacles, *Balanus eburneus* and *B. improvisus*, the hydroid, *Obelia longissima*, the amphipod, *Corophium insidiosum*, the polychaete, *Polydora ligni*, the mussel, *Mytilus edulis*, and the ship borer, *Teredo navalis*. Spatial trends in species richness were evident within the harbor. Species richness at Fort Hale and Harbor Station, was higher than at Long Wharf for most years. General seasonal trends in species richness were not consistent. The maximum number of species occurred in either spring,

TABLE 5-8. SPECIES DISTRIBUTION (BY STATION) FOR SHORT- AND LONG-TERM PANELS COMBINED.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	1971			1972			1973			1974			1975			1976			1977		
	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW
ALGAE																					
Chlorophyceae																					
<i>Enteromorpha</i> sp.													x			x			x		
<i>Polysiphonia</i> sp.													x			x					
<i>Ulva lactuca</i>									x												
PORIFERA																					
<i>Halichondria bowerbankii</i>																x					
Unidentified porifera													x					x			
HYDROIDEA																					
<i>Campanularia</i> spp.																					
<i>Halecium</i> sp.							x						x			x			x		
<i>Obelia longissima</i>	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Obelia</i> sp.																					
Unidentified hydrozoan						x															
ANTHOZOA																					
<i>Actinaria</i>									x							x					
<i>Diadumene leucolena</i>										x											
<i>Metridium senile</i>											x										
Sagartidae																					
<i>Sagartia</i> sp.						x															
Unidentified anthozoan																					
PLATYHELMINTHES																					
<i>Euplana gracilis</i>																					
<i>Stylocheus ellipticus</i>	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Nematodea																					

Continued

TABLE 5-8. (Continued)

	1971			1972			1973			1974			1975			1976			1977		
	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW	FH	HS	LW
POLYCHAETA																					
<i>Amphitrite</i> sp.																				x	
<i>Autolytus cornutus</i>																				x	
<i>Autolytus</i> sp.																				x	
<i>Eteone heteropoda</i>																				x	x
<i>Eteone</i> sp.																				x	
<i>Eulalia</i> sp.																					
<i>Eulalia bilineata</i>																				x	
<i>Eulalia viridis</i>																				x	
<i>Eumida sanguinea</i>																				x	x
<i>Fabricia sabella</i>																				x	
<i>Harmothoe extenuata</i>																				x	
<i>Hydroides dianthus</i>																				x	x
<i>Hydroides</i> spp.																				x	
<i>Lepidonotus squamatus</i>																				x	
<i>Nereis arenacedonota</i>																				x	
<i>Nereis succinea</i>	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Phyllodoceidae	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
<i>Phyllodoce</i> sp.																					
<i>Podarke obscura</i>																					
<i>Polydora ligni</i>																					
<i>Polydora socialis</i>																					
<i>Polydora</i> sp.																					
Mudworm tubes																					
Polynoidae																					
<i>Potamilla neglecta</i>																					
Sabellidae																					
<i>Sabella microphthalma</i>																					
<i>Sabellaria vulgaris</i>																					

Continued

TABLE 5-8. (Continued)

	1971		1972		1973		1974		1975		1976		1977	
	FH	HS LW	FH	HS LW	FH	HS LW	FH	HS LW	FH	HS LW	FH	HS LW	FH	HS LW
Serpulidae			x		x		x	x	x	x	x	x		
Serpulid tubes				x		x								
<i>Spio filicornis</i>											x			x
Spionidae														
<i>Stauroneis rudolphi</i>										x				
<i>Streblospio benedicti</i>									x					
Syllidae											x		x	x
Terebellidae													x	x
<i>Terebella lapidaria</i>														
Unidentified polychaeta					x	x			x					
MOLLUSCA														
<i>Crassostrea</i> spp.														
<i>Crassostrea virginica</i>	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Crepidula fornicata</i>	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Crepidula plana</i>			x	x	x	x	x	x	x	x	x	x	x	x
<i>Crepidula</i> spp.														
<i>Doridella obscura</i>													x	
<i>Littorina saxatilis</i>														
<i>Mitrella lunata</i>														
<i>Mya arenaria</i>													x	x
<i>Mytilus edulis</i>													x	x
<i>Nucula</i> sp.			x	x	x	x	x	x	x	x	x	x	x	x
<i>Teredo navalis</i>														
Teredinidae	x	x	x	x	x	x	x	x	x	x	x	x		
<i>Thracia septentrionalis</i>														
<i>Urosalpinx cinereus</i>							x		x				x	x
Acarina											x			

Continued

TABLE 5-8. (Continued)

	1971	1972	1973	1974	1975	1976	1977
	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW	FH HS LW
ISOPODA							
<i>Jaera marina</i>		x					x
<i>Limnoria</i> sp.				x	x		
<i>Limnoria tripunctata</i>				x			
CIRRIPIEDIA							
<i>Balanus crenatus</i>	x	x	x	x	x	x	x
<i>Balanus eburneus</i>	x	x	x	x	x	x	x
<i>Balanus improvisus</i>	x	x	x	x	x	x	x
<i>Balanus</i> spp.	x	x	x	x	x	x	x
AMPHIPODA							
<i>Ampithoe longimana</i>						x	
<i>Ampithoe valida</i>						x	x
<i>Ampithoe</i> sp.							
<i>Aeolid amphipod</i>					x		
Caprellidae				x			
<i>Caprella penantis</i>						x	x
<i>Corophium insidiosum</i>						x	x
<i>Corophium</i> sp.	x	x	x	x	x	x	x
Gammaridea							
<i>Gammarus anulatus</i>				x		x	
<i>Gammarus locusta</i>		x					
<i>Gammarus lawrencianus</i>							x
<i>Gammarus</i> sp.							x
Ischyroceridae							
<i>Ischyroceros anguipes</i>						x	
<i>Jassa falcata</i>	x						
<i>Microdeutopus anomalus</i>						x	x
<i>Microdeutopus gryllotalpa</i>		x			x	x	x

Continued

fall or summer. These long-term panel distributions are probably related to larval settlement as they coincide with peak spawning periods. Settlement on short-term panels occurs in early spring and summer for most taxa such as *Obelia* spp., *Corophium insidiosum*, *Polydora ligni*, and *Mytilus edulis*. Fall settlement is seen as a smaller peak in some species (e.g., *Balanus* spp., *Polydora ligni*) and with *Balanus*, is generally the result of spawning from barnacles that settled in the spring (Grave, 1933).

Analysis of the New Haven Harbor exposure panel data shows no change from preoperational to operational years attributable to power station activities. Fluctuation in seasonal and annual distributions of panel-community members is characteristic of the assemblage. Similar patterns are seen in other fouling panel studies in the greater Long Island Sound area. The harbor in general appears to support a productive, relatively stable panel community which has not been impacted by the New Haven Harbor Station operation.

LITERATURE CITED -- EXPOSURE PANELS

- Anger, K. 1977. Benthic invertebrates as indicators of organic pollution in the western Baltic Sea. *Int. Review Ges. Hydrobiol.* 16(2):187-203.
- Battelle: William F. Clapp Laboratories. 1973. A monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Prepared for the Northeast Utilities Service Company. 16 sections.
- _____. 1977. A monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Annual Report of Ecological and Hydrographic Studies, 1976. Prepared for Northeast Utilities Service Company, Berlin, Connecticut. 7 sections.
- _____. 1978. A monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Annual Report of Ecological and Hydrographic Studies, 1977. Prepared for Northeast Utilities Service Company, Berlin, Connecticut. 9 sections.
- Blake, J.A. 1969. Reproduction and larval development of *Polydora* from northern New England (Polychaeta:Spionidae). *Ophelia*. 7:1-63 (December 1969).
- Calder, D.R. and M.C. Brehmer. 1967. Seasonal occurrence of epifauna on test panels in Hampton Roads, Virginia. *Int. Jour. Ocean and Limnol.* 1:149-164.
- Clapp, William F. Laboratories. 1937. Marine piling investigation, 1935-1936. Prepared by the New England Committee on Marine Piling Investigation. 249 pp.
- Cory, R.L. and J.W. Nauman. 1969. Epifauna and thermal additions in the Upper Patuxent River estuary. *Chesapeake Science*. Vol. 10: 210-217.
- Crisp, D.T. and H. Barnes. 1954. The orientation and distribution of barnacles at settlement, with particular reference to surface contour. *J. Anim. Ecol.* 23:142-162.
- _____ and H.G. Stubbings. 1957. The orientation of barnacles to water currents. *J. Anim. Ecol.* 26:179-196.
- Culliney, J.L. 1975. Comparative larval development of the shipworms *Bankia gouldi* and *Teredo navalis*. *Marine Biol.* 29:254-251.
- Daro, M.M. 1970. L'association des amphipodes et *Polydora ciliata* à la côte Belge. *Neth. J. Sea Res.* 5:96-100.

- _____ and P. Polk. 1973. The autecology of *Polydora ciliata* along the Belgian coast. *Neth. J. Sea Res.* 6:130-140.
- Dean, T.A. and V.J. Belles. 1975. Seasonal and spatial distribution of epifauna in the Pamlico River estuary, North Carolina. *J. Elisha Mitchell Sci-Soc.* 91:1-12.
- Enright, J.T. 1977. Power plants and plankton. *Marine Pollution Bulletin* 8(7):158-163.
- Feldmeth, C. and M. Alpert. 1977. The effect of temperature on the distribution and biomass of *Mytilus edulis* in the Alamitas Bay area. *Veliger.* 20:39-42.
- Galtsoff, P.S. 1964. The American oyster, *Crassostrea virginica* Gmelin. *Fish. Bull. of Fish and Wildl. Serv.* 64:4-29.
- Grassle, J.F. and J.P. Grassle. 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. *J. Mar. Res.* 32:253-284.
- Grave, B.H. 1933. Rate of growth, age at sexual maturity and duration of life of certain sessile organisms at Woods Hole, Massachusetts. *Biol. Bull.* 65:375-386.
- Hillman, R.E. 1973. Environmental monitoring through the use of exposure panels. *IN: S. B. Saila (ed.). Fisheries and Energy Production: A Symposium.* Lexington Books, Lexington, Massachusetts. pp. 55-76.
- Hoagland, K.E., L. Crockett and M. Rochester. 1978. Analysis of populations of boring and fouling organisms in the vicinity of the Oyster Creek Nuclear Generating Station. Prepared for U.S. Nuclear Regulatory Commission. 44 pp.
- Leppakoski, E. 1975. Assessment of degree of pollution on the basis of macrozoobenthos in marine and brackish-water environments. *ACTA. Academiae Aboensis. Series B, Vol. 35.* pp. 1-90.
- Nauman, J.L. and R.L. Cory. 1969. Thermal addition and epifaunal organisms at Chalk Point, Maryland. *Chesapeake Science.* Vol. 10 (3+4):218-226.
- Naylor, E. 1965. Biological effects of a heated effluent in docks at Swansea, S. Wales. *Zoo. Soc. Lond. Proc.* 144:253-267.
- Normandeau Associates, Inc. 1971. Ecological considerations of the Coke Works Site, New Haven Harbor, Connecticut. Prepared for The United Illuminating Company, New Haven, Connecticut. 64 pp.
- _____. 1973a. New Haven Harbor Ecological Studies, New Haven, Connecticut. Annual Report 1971-1972. Prepared for The United Illuminating Company, New Haven, Connecticut. 208 pp.

- _____. 1973b. Bridgeport Harbor Ecological Studies 1971-1972. Prepared for The United Illuminating Company, New Haven, Connecticut. 196 pp.
- _____. 1974a. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1972-1973. Prepared for The United Illuminating Company, New Haven, Connecticut. 215 pp.
- _____. 1974b. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Interim Report May-December 1973. Prepared for The United Illuminating Company, New Haven, Connecticut. 199 pp.
- _____. 1974c. Stamford Harbor Ecological Studies. Final Report 1971-1973. Prepared for Northeast Utilities Service Company. 159 pp.
- _____. 1975a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1974. Prepared for The United Illuminating Company, New Haven, Connecticut.
- _____. 1975b. Ecological studies conducted at selected sites in New Haven Harbor, Connecticut. Prepared for The United Illuminating Company, New Haven, Connecticut. 114 pp.
- _____. 1976a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1975. Prepared for The United Illuminating Company, New Haven, Connecticut. 312 pp.
- _____. 1976b. New Haven Harbor thermal regime during operation of the New Haven Harbor Station September 1975. Prepared for The United Illuminating Company, New Haven, Connecticut. 31 pp.
- _____. 1976c. New Haven Harbor Ecological Monitoring Studies, New Haven Harbor, Connecticut. Acute Toxicity Studies. Prepared for The United Illuminating Company, New Haven, Connecticut. 64 pp.
- _____. 1977a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1976. Prepared for The United Illuminating Company, New Haven, Connecticut. 376 pp.
- _____. 1977b. Thermal surveys: New Haven Harbor, summer and fall 1976. Prepared for The United Illuminating Company, New Haven, Connecticut. 70 pp.
- _____. 1977c. Piscataqua River Ecological Studies, 1976. Monitoring Study Report No. 7. Prepared for Public Service Company of New Hampshire.

- _____. 1978. New Haven Harbor Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1977. Prepared for The United Illuminating Company, New Haven, Connecticut. 359 pp.
- Osmann, R.W. 1977. Establishment and development of a marine epifaunal community. Ecological Monographs. Vol. 47(1):37-63.
- Pearce, J.B. 1969. Thermal addition and the benthos, Cape Cod Canal. Chesapeake Science. 10(314):227-233.
- Pomerat, C.M. and C.M. Weiss. 1946. The influence of texture and composition of surface on the attachment of sedentary marine organisms. Biol. Bull. 91:57-65.
- Raytheon. 1970a. New Haven Harbor Plankton Survey, April-May 1970. Prepared for The United Illuminating Company, New Haven, Connecticut. 49 pp.
- _____. 1970b. New Haven Harbor Ecological Survey, June-December 1970. Prepared for The United Illuminating Company, New Haven, Connecticut. 179 pp.
- _____. 1971. New Haven Harbor Ecological Survey, December-April 1971. Prepared for The United Illuminating Company, New Haven, Connecticut. 11 sections.
- Rosenberg, R. 1976. Benthic faunal dynamics during succession following pollution abatement in a Swedish estuary. Cikos. 27:414-427.
- Tinsman, J.C. and D.L. Maurer. 1974. Effects of thermal effluent on the American oyster. pp. 223-236 IN: Thermal Ecology. A.E.C. Symposium Series.
- TRIGOM-PARC. 1974. A socio-economic and environmental inventory of the North Atlantic region. Prepared for Bureau of Land Management, Marine Minerals Division, South Portland, Maine. 8 Volumes.
- Turner, R.D. 1966. A survey and illustrated catalogue of the Terebrinidae. Museum of Comparative Zoology. 265 pp. Cambridge, Massachusetts.
- Wass, M.L. 1967. Biological and physiological basis of indicator organisms and communities. IN: T.A. Olson and F.J. Burgess. Pollution and Marine Ecology. Interscience, New York. pp. 271-283.
- Widdows, J. 1973. Effect of temperature and food on the heartbeat, ventilation rate and oxygen uptake of *Mytilus edulis*. Mar. Biol. (Berlin). 20(4):265-276.
- Woods Hole Oceanographic Institution. 1952. Marine fouling and its prevention. 338 pp.

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

6.0 SUBTIDAL BENTHOS

by David J. Hartzband and Andrew J. McCusker
Normandeau Associates, Inc.
Bedford, N. H.

Richard McGrath and Allan B. Michael
Taxon, Inc.
Salem, Massachusetts

Donald A. Rhoads
Department of Geology and Geophysics
Yale University
New Haven, Connecticut

TABLE OF CONTENTS

	PAGE
INTRODUCTION.	6-1
METHODS	6-2
R & M Program	6-2
NAI Program	6-6
Data Analysis	6-6
CHARACTERIZATION OF NEW HAVEN HARBOR.	6-9
Species Composition	6-10
Species Richness.	6-26
Faunal Density.	6-28
Diversity	6-34
Within-Station Variability.	6-37
Classification Analysis	6-41
ANALYSIS OF IMPACTS	6-53
Species Richness.	6-55
Species Density	6-56
Diversity	6-59
SUMMARY	6-59
LITERATURE CITED.	6-62

LIST OF FIGURES

	PAGE
6-1. New Haven Harbor benthic station location map.	6-3
6-2. Spatial distribution of New Haven Harbor character- istic benthic Annelid species with frequency of occurrence values.	6-18
6-3. Spatial distribution of New Haven Harbor character- istic benthic mollusc species with frequency of occurrence values	6-20
6-4. Mean densities (individuals/m ²) of New Haven Harbor characteristic species (averaged for all samples in which species was present). Number of samples in which species was found is indicated by numeral at top of bar.	6-22
6-5. Mean total species per station for Morris Cove and Inner Harbor stations, May 1973 through October 1977 . .	6-30
6-6. Faunal densities (individuals/m ²) for Morris Cove deep water (Stations E,F); Morris Cove shallow water (Stations A,G) and Inner Harbor (Stations 5, 10)	6-32
6-7. Brillouin diversity (H _b) histograms for Morris Cove, Inner Harbor and combined data (R & M data only).. . . .	6-35
6-8. Station grouping dendrograms from normal (Q-mode) cluster analysis, by sampling date	6-42
6-9. Spatial distribution of station groups* identified from dendrograms (Figure 6-7).	6-46
6-10. Inverse (R-mode) dendrograms from cluster analysis, by year (Refer to Table 6-3 for species codes)..	6-47

LIST OF TABLES

	PAGE
6-1. DATES OF SUBTIDAL BENTHIC SAMPLING FROM MAY 1973 THROUGH JANUARY 1978 AT ALL STATIONS.	6-4
6-2. NEW HAVEN HARBOR BENTHIC SPECIES LIST	6-11
6-3. ABRIDGED BENTHIC SPECIES LIST*.	6-14
6-4. DISTRIBUTION OF NEW HAVEN HARBOR CHARACTERISTIC BENTHIC SPECIES AMONG STATION GROUPS.	6-17
6-5. TOTAL NUMBER OF SPECIES PER STATION, MAY 1973 - JANUARY 1978.	6-27
6-6. FAUNAL DENSITY (MEAN INDIVIDUALS/m ²) BY STATION MAY 1973 THROUGH JANUARY 1978	6-29
6-7. COEFFICIENT OF VARIATION (CV) (% OF MEAN) VALUES FOR NUMBER OF SPECIES, NUMBER OF INDIVIDUALS AND DIVERSITY, 1977, BASED ON 3 REPLICATE SAMPLES	6-38
6-8. COEFFICIENT OF VARIATION (CV) (% OF MEAN) VALUES AVERAGED FOR NEW HAVEN HARBOR, 1977; INNER HARBOR AND MORRIS COVE SITES AND CV VALUES FROM PLYMOUTH, MASSACHUSETTS.	6-39
6-9. BENTHIC SPECIES CHARACTERISTIC OF GROUP STATIONS FOR FOUR STATION GROUPS (RANKED BY FREQUENCY OF OCCURRENCE).	6-49
6-10. TRENDS IN MEAN DENSITY FOR 14 CHARACTERISTIC SPECIES EVALUATED VIA SPEARMAN'S RHO.	6-57
6-11. RESULTS OF PAIRED T-TESTS FOR FAUNAL DENSITY CHANGES FOR ALL POSSIBLE PAIRS OF YEARS.	6-58
6-12. RESULTS OF PAIRED T-TESTS FOR DIVERSITY (H') CHANGES FOR ALL POSSIBLE PAIRS OF YEARS.	6-60

6.0 SUBTIDAL BENTHOS

by David J. Hartzband and Andrew J. McCusker
Normandeau Associates, Inc., Bedford, N. H.

Richard McGrath and Allan B. Michael
Taxon, Inc., Salem, Mass.

Donald A. Rhoads
Department of Geology and Geophysics, Yale University, New Haven, Conn.

INTRODUCTION

Study of the population dynamics of benthic species can provide important insights into long-term disturbance history of the seafloor. Benthic species, especially infauna, are relatively immobile as adults and therefore are exposed to changes in the ambient environment. Changes in environmental quality are reflected both in selective mortality of adults and also in the recruitment success of newly settled larvae.

The temporal and spatial persistence of the species composition at a particular location reflects the temporal and spatial stability of the habitat. In polluted, or otherwise dynamically changing environments, the benthos are in a continual state of successional change. The species composition of such a low-order successional stage is very unpredictable. In less variable physical and chemical habitats, the benthic fauna can maintain its structure for longer periods of time. Biotic interactions can develop and the organisms can modify their environment to some degree. This internal "stasis" is manifested in persistent and predictable species associations.

Long-term observations are necessary to document the dynamics of benthic populations. Without the time perspective, it is presently not possible to distinguish a pioneer benthic stage from a persistent climax community.

The purpose of this study was to detect any acute or long-term changes in the New Haven Harbor benthos which might be attributable to

power station impact. Direct contact of the buoyant thermal plume with the subtidal benthic habitat is unlikely (see Section 3.0). However, benthic populations might be indirectly affected by reduced larval recruitment due to larval mortality from entrainment through the condenser cooling system or thermal shock through contact with the plume outside of the power station. Further impacts could result from any alterations in either predator or prey populations.

This report summarizes data collected by two separate investigations which were conducted concurrently from 1974 through 1978. The first of these studies has been under the direction of Normandeau Associates, Inc. (NAI) since 1970. The NAI benthic infaunal program was part of the more comprehensive New Haven Harbor Station Ecological Monitoring Studies (NHHSEMS). The second benthic program was conducted by D. C. Rhoads and A. D. Michael (R&M) of Yale University and Taxon, Inc., Salem, Massachusetts, respectively. The latter study was initiated in 1974 as part of a program responding to the "special benthic study" provision [Item 4(A)(2)] of NHHS's 1973 NPDES discharge permit. This study has been independent of the NAI program and R&M reports have been included as Appendices to the NHHSEMS Annual reports.

METHODS

Though the two studies employed similarly sized sampling devices and the same mesh size for sieving, station locations and sampling schedules for the two studies were different. Station locations for both studies are shown in Figure 6-1 and sampling dates are listed in Table 6-1.

R & M Program

The R&M sampling program comprised 19 (later 20) stations which were sampled four times a year (March, August, October, December-

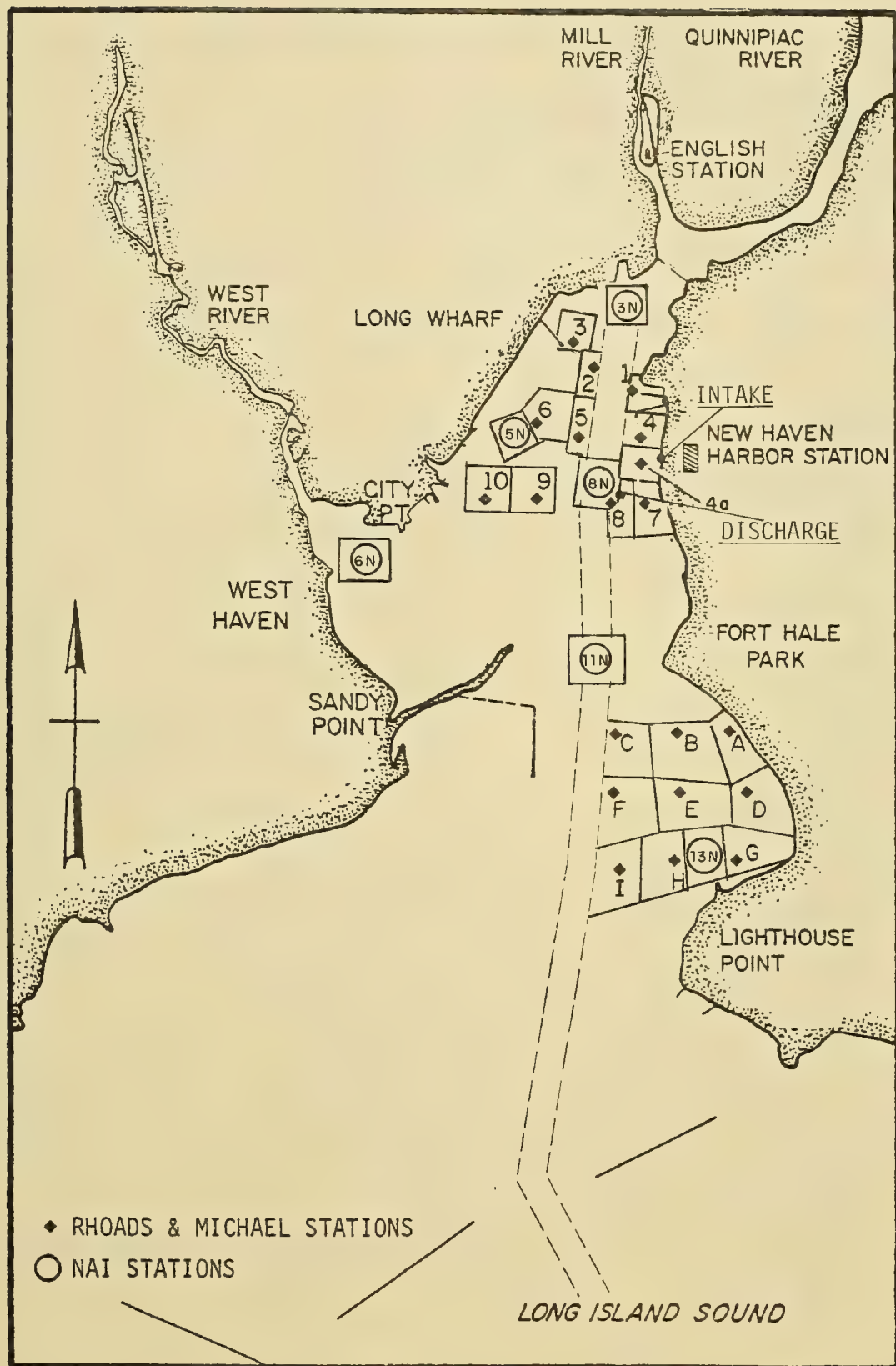


Figure 6-1. New Haven Harbor benthic station location map. New Haven Harbor Ecological Study Summary Report, 1979.

TABLE 6-1. DATES OF SUBTIDAL BENTHIC SAMPLING FROM MAY 1973 THROUGH JANUARY 1978 AT ALL STATIONS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

STATION	5*	8	3	5	8	9	10	12	3	6	8	10	12	2	3	6	8	10	1
1973	1973	1974	1974	1974	1974	1974	1974	1974	1975	1975	1975	1975	1975	1976	1976	1976	1977	1977	1978
3N	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
5N	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
6N	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
8N	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11N	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
13N	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
2	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
3	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
4	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
4a	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
5	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
6	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
7	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
8	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
9	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
10	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
A	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
B	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
C	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
D	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
E	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
F	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
G	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
H	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---
I	---	---	X	---	X	---	---	X	---	---	---	---	---	---	---	---	---	---	---

x = Sample taken
 --- = Not sampled
 * = Month

January) from March 1974 through January 1978. Data for January 1978, beyond the October 1977 cutoff for this report, are included in this case because they complete the data set for the fourth and final year of this special program. Ten stations (1-10) were initially established in the inner harbor adjacent to the power plant site. One additional inner harbor station (4a), located between the intake structure and discharge pipe, was added in 1976. This station is characterized by a coarse-grained bottom relatively free from organic detritus. This is an unusual condition for an inner-harbor substrate and is probably related to dredging activity.

A control or reference site was located outside of the immediate vicinity of the plant to reduce the possibility that both sites might be impacted by the thermal discharge. Variation in hydrographic parameters between harbor areas limited the selection of a control site. Nine stations (A-I) were therefore selected in Morris Cove as comparison sites. Although the Morris Cove stations represent a slightly different hydrographic regime, the range of sediment types is similar to that found near the plant.

At each sampling date in 1974 and 1975, duplicate samples were taken with a 0.04 m^2 Van Veen grab. Sampling intensity was increased to triplicates beginning in 1976 in order to better estimate spatial patchiness of the benthos. Samples were returned to the laboratory and sieved through a 1.0 mm mesh stainless steel sieve. An 80 cm^2 subsample, at selected stations, was washed through a 0.297 mm mesh sieve. Collection of the 0.297 mm subsamples was suspended after analysis of the subsamples for 1974 showed that no unique faunal components were missed by using a 1.0 mm sieve. Additional analysis of six 0.297 mm samples collected in 1976-1977 confirmed the earlier result. All sieved samples were fixed in formalin, stained with rose bengal to facilitate sorting, and preserved in 70% ethanol.

NAI Program

The NAI sampling program was a continuation of a baseline study initiated under NAI direction by the Raytheon Company in 1970. The present methodology was standardized in 1973, and data collected prior to 1973 are not considered in this report, except as a qualitative reference.

Sampling was done with a 0.053 m^2 Ponar grab sampler (recoverable volume = 7450 cm^3). Five replicate samples were collected at each of three stations (5, 8 and 13) during 1973 and 1974 and six stations (3, 5, 6, 8, 11, 13) from 1975 through 1977. As some of the stations bear the same numerical designation as some R & M stations, all NAI stations will hereafter be designated with an "N" suffix in all text, tables and figures. Samples were sieved through a 1.0 mm mesh sieve, and preserved in a 5% formalin solution in the field.

NAI stations were designated as either inner harbor (3N, 5N, 6N), shipping channel (8N, 11N) or outer harbor (13N). The inner harbor NAI stations are generally in shallower areas more distant from the power station than are the R & M stations. Stations 8N and 11N are not directly comparable with any of the R & M stations, while Station 13N is spatially contiguous with the Morris Cove control stations.

Data Analysis

Data analyses included calculation of information-theory diversity indices (Shannon-Weaver, H' ; Brillouin, H) and related values (J' , $H'_{\max}$, $H'_{\min}$). These indices were calculated separately for each replicate. Data processing was done at the Woods Hole Oceanographic Institution (WHOI) computing facility. The Shannon-Weaver formula is expressed by:

$$H' = \sum_{i=1}^S p_i \log p_i$$

where: p_i = proportion of the i^{th} species in the sample. The Brillouin index is calculated as:

$$H = \frac{1}{N} \log \frac{N!}{n_1! n_2! \dots n_s!}$$

where: N = total individuals

S = number of species

n_i = number of individuals for the i^{th} species.

These two diversity indices have been used somewhat interchangeably by ecologists and the decision as to which is appropriate is based upon theoretical considerations best summarized by Pielou (1966, 1975). It is convenient to consider H (Brillouin) as representing the diversity present in the sample itself and H' (Shannon-Weaver) to be an estimator of the diversity in the population from which the sample is drawn. In practice, the choice of an index is not of prime importance because both are highly correlated ($r = 0.9725$ for a random sample of data from the present study).

J' , or evenness, is a measure of how equally the various component species are represented in the population in terms of their numerical density, and is calculated from:

$$J' = \frac{H'}{\log_s}$$

where: s = number of species.

H'_{max} is the highest value that H' can assume given a certain number of species. This occurs when the J' value is at a maximum, which is when all species are represented equally. H'_{max} is calculated by:

$$H'_{\text{max}} = - \frac{1}{S} \log \frac{1}{S} = \log_s$$

$H'_{\min}$ is defined as the lowest possible diversity (H') value for a population with a given number of species. This occurs when all species but one are represented by a single individual and is calculated as:

$$H'_{\min} = \frac{1}{N} \log \frac{N!}{(N-S+1)!}$$

Normal (Q-mode) and inverse (R-mode) cluster analyses were performed on data from each sampling period separately and for all sampling periods combined. In all cases the mean value of all replicates was used for each species. All classification analyses were computed using the program SPSTCL at the WHOI computing center. No transformations were applied to the data. The similarity coefficient used was percent similarity (standardized Bray-Curtis) and the clustering strategy was group average sorting.

Normal cluster analyses were conducted on the results for individual sampling events from the R & M study from March 1974 to January 1978. NAI samples that had been collected within one month of the R & M samples were included in the analyses. Normal and inverse analyses were also computed on the annual data-set for each of the four years. In each inverse analysis only the 40 most abundant species for the particular year were considered. Nodal analyses, in which the normal and inverse classification results are compared in a single matrix, were prepared for 1974 and 1977. Because no consistent station groupings had been identified at the time the nodal analyses were computed, constancy values were calculated for individual stations and species. The nodal analyses did not add any new information and, hence, are not presented in this report.

Means of various population parameters (species richness, faunal density, diversity) were tested for significant differences over space and time using standard paired and unpaired Student's *t* procedures. In all cases two-tailed tests were used with a rejection criterion of 0.05. Spearman's coefficient of rank correlation was used to

evaluate trends in certain parameters over time. Collections were ranked in chronological order and the parameter being examined was ranked according to its position in the range of values expressed in the time series. A rejection region of 0.05 was used consistently in this procedure.

Numbers of taxa and individuals per sample were analyzed for differences by years, seasons and stations via three-way ANOVA. This analysis was performed by the NAI Technical Data Processing & Analysis Group. In order to incorporate the most temporally extensive but consistent data base possible into this analysis, only data from the spring and summer samplings at Stations 5N, 8N and 13N over the 1973-1977 period were used. All data were standardized by a $\log_{10}(X + 1)$ transformation. The null hypotheses under consideration were: 1) the experimental stations in general would not exhibit changes over years, or 2) that Stations 5N and 8N would show changes with the inception of station operation while the Morris Cove Station 13N would not.

CHARACTERIZATION OF THE NEW HAVEN HARBOR BENTHIC INFAUNA

As might be expected in a temperate, shallow, estuarine embayment, the subtidal benthos in New Haven Harbor is spatially and seasonally variable in terms of species composition, faunal densities and species richness. In addition, the New Haven Harbor benthos has been characterized by extreme year-to-year variability in these parameters. The most abundant fauna are either opportunistic, have short life spans, or are highly mobile species that are rarely present through a full annual cycle. The parameters of species richness, faunal density and diversity are considered in detail and examined for spatial and seasonal patterns, particularly as they are related to changes in the environmental condition of the harbor. Those species commonly found in the area which, on the basis of abundances and frequencies of occurrence, best characterize the benthic assemblage of New Haven Harbor are discussed in greater detail. Faunal groupings are identified and their

spatial distributions and within-station variability in the data is addressed. The information developed in this section provides a framework for the analysis of potential impacts of New Haven Harbor Station. The high spatial and temporal faunal variability which characterized the New Haven Harbor benthos over the period of this study, prevented us from utilizing more sophisticated data-reduction techniques which can ordinarily be employed in analyses of benthic faunal data. We therefore had to take an interpretive approach that relies heavily on the more qualitative and descriptive aspects of the data.

Species Composition

A master species list (Table 6-2) was compiled from the combined data of Normandeau Associates, Inc. (NAI) from 1973-1977 and the Rhoads and Michael (R & M) 1974-1977 program. The list comprises 302 species or higher taxa: all major macrofaunal groups identified from previous studies of southern New England estuaries are represented.

The master species list was examined for inconsistencies due to changes in taxonomic identification procedures and a number of minor taxonomic discrepancies were found. Most of these problems were resolved merely by consulting appropriate systematic sources. Several inconsistencies in the list were due only to the level of identification: Porifera, Cnidaria, Platyhelminthes and Chordata were generally identified to the species level in NAI data but only to phylum by R & M. Similarly, the *Eulalia* sp. included in the NAI list was assumed to be *Eulalia viridis* as identified by R & M. Some inconsistencies between the two lists arose as a result of differences in the literature source used in faunal identifications. This type of discrepancy resulted in several minor changes. The bivalve genus *Callocardia* was relisted under its more current name *Pitar*; the amphipod genus *Carinogammarus* was updated to *Gammarus*; *Crangon vulgaris* was assumed to be *Crangon septemspinosa*; and the polychaete identified as *Eteone alba* was assumed to be *Eteone lactea*. Finally, a bivalve that had been variously identified

TABLE 6-2.

Code	Code	Code	Code	Code	Code
P	A	A	A	A	A
PORIFERA	ANNELEIDA (Continued)	ANNELEIDA (Continued)	ANNELEIDA (Continued)	ANNELEIDA (Continued)	ANNELEIDA (Continued)
Cliona celata Halichondria bowerbanki Halicionia oculata Hymeniacidon heliophila Microcionia prolifera	P1	Dispio uncinata	A5	Polydora sp.	A49
	P2	Drilonereis longa	A6	Potamilla neglecta	A50
	P3	Eteone lactea	A8	Potamilla reniformis	A51
	P4	Eteone heteropoda	A9	Sabella microphthalmia	A52
	P5	Eteone sp.	A10	Sabella vulgaris	A53
CNIDARIA		Eulalia viridis	A11	Scolecoplepides viridis	A54
		Eulalia sp.	A12	Scoloplos acutus	A55
		Eumida sanguinea	A13	Scoloplos fragilis	A56
	CN	Exogone sp.	A14	Scoloplos sp.	A57
		Fabricia sabella	A15	U/I Serpulidae	A58
Hydroida Bougainvillea anemone Bougainvillea caroliensis Metridium dianthus Metridium senile Obelia longissima Sargartia modesta	CN1	Dodecaceria corallii	A16	Spio filicornis	A59
	CN2	Glycera americana	A17	Spio setosa	A60
	CN3	Glycera dibranchiata	A18	Spiochaetopterus oculatus	A61
	CN4	Harmothoe extenuata	A19	Spio sp.	A62
	CN5	Harmothoe imbricata	A20	Spirorbis spirillum	A63
	CN6	Hydroides dianthus	A21	Spirorbis borealis	A64
	CN7	Lepidasthenia grimaldii	A22	Stauroneis rudoiphi	A65
		Lepidonotus squamatus	A23	Sthenelais boa	A66
		Lepidonotus sublevis	A24	Streptosio benedicti	A67
	PL	Lumbrineris tenuis	A25	Tharyx acutus	A68
		Lycastopsis pontica	A26	Tharyx sp.	A69
		Maldane sarsi	A27	U/I Phyllocodidae	A70
POLYGLADIA Turbellaria Planocera nebulosa Polychaerus caudatus Stylochus ellipticus Trigonoporus folium	PL1	Maldanopsis elongata	A28	U/I Polychaeta	A71
	PL2	Mediomastus ambiseta	A29	U/I Sabellidae	A72
	PL3	Myriochela heeri	A30	U/I Syllidae	A73
	PL4	Nephtys incisa	A31	Euchone rubrocincta	A74
	PL5	Nereis succinea	A32	Eusyllis sp.	A75
	PL6	Nereis arenaceodonta	A33	Polycirrus medusa	A76
NEMATODA	N	Nereis grayi	A34	Amphareta affinis	A77
		Nereis virens	A35	Amphareta arctica	A78
		Onuphis conchylega	A36	Polycirrus eximus	A79
RHYNCHOCOLA	R	Oligochaeta	A37	Heteromastus filliformis	A80
		Paranaitus speciosa	A38	Owenia fusiformis	A81
		Pectinaria gouldii	A39	Nereis sp.	A82
Cerebratulus lactea Tubulanus pellucidus	R1	Phyllodoce sp.	A40	Nephtys caeca	A83
	R2	Phyllodoce mucosa	A41	Maldanidae	A84
ANNELEIDA	A	Phyllodoce arenae	A42	Brania wellfleetensis	A85
		Platynereis dumerilii	A43	Paraprionosyllis longicerrata	A86
		Podarke obscura	A44	Nerineides agilis	A87
		Polycirrus phosphorea	A45	Stenelais limicola	A88
Amphitrite johnstoni Capitella capitata Clymenella zonalis Chone infundibuliformis	A1	Polydora ligni	A46	Phereusa affinis	A89
	A2	Polydora socialis	A47	Amphitrite affinis	A90
	A3			Polynoidea	A91
	A4			Capitellidae	A92

Continued

TABLE 6-2. (Continued)

MOLLUSCA (Continued)	M	CRUSTACEA	C	CRUSTACEA (Continued)	C	ECTOPROCTA	B
<i>Macoma tenta</i>	M26	<i>Balanus balanus</i>	C1	<i>Jassa falcata</i>	C48	<i>Bowerbankia gracilis</i>	B1
<i>Macoma balthica</i>	M27	<i>Balanus eburneus</i>	C2	<i>Lembo smithi</i>	C49	<i>Canopeum reticulum</i>	B2
<i>Mercenaria mercenaria</i>	M28	<i>Balanus improvisus</i>	C3	<i>Leptochaeirus pinguis</i>	C50	<i>Cryptosula pallisiana</i>	B3
<i>Modiolus modiolus</i>	M29	<i>Balanus balanoides</i>	C4	<i>Libinia emarginata</i>	C51	<i>Electra crustulenta</i>	B4
<i>Modiolus demissus</i>	M30	<i>Neomysis americana</i>	C5	<i>Leptochellia savignyi</i>	C52	<i>Schizoporella unicornis</i>	B5
<i>Mulinia lateralis</i>	M31	<i>Mysis stenolepis</i>	C6	<i>Melitta nitida</i>	C53		
<i>Mya arenaria</i>	M32	<i>Diastylis polita</i>	C7	<i>Microdeutopus gryllotalpa</i>	C54		
<i>Mytilus edulis</i>	M33	<i>Leptocuma minor</i>	C8	<i>Neopanope saui</i>	C55	ECHINODERMATA	E
<i>Mytella planulata</i>	M34	<i>Oxyurostylis smithi</i>	C9	<i>Neopanope texana</i>	C56		
<i>Nucula proxima</i>	M35	<i>Chiridotea comca</i>	C10	<i>Ovalipes ocellatus</i>	C57	<i>Arabacia punctata</i>	E1
<i>Nucula tenuis</i>	M36	<i>Edotea triloba</i>	C11	Ostracoda	C58	<i>Asterias forbesi</i>	E2
<i>Nucula sp.</i>	M37	<i>Edotea sp.</i>	C12	<i>Pontogeneia inermis</i>	C59	<i>Asterias vulgaris</i>	E3
<i>Nassarius trivittatus</i>	M38	<i>Idotea balthica</i>	C13	<i>Pagurus pollicaris</i>	C60	<i>Asterias sp.</i>	E4
<i>Ostomia bisuturalis</i>	M39	<i>Jaera marina</i>	C14	<i>Pagurus longicarpus</i>	C61	U/I Asteroidea	E5
<i>Polynices duplicata</i>	M40	<i>Nerocila munda</i>	C15	<i>Palaemonetes intermedius</i>	C62	Holothuroidea	E6
<i>Polynices heros</i>	M41	<i>Ampelisca abdita</i>	C16	<i>Palaemonetes pugio</i>	C63		
<i>Petricola pholadiformis</i>	M42	<i>Ampelisca vadorum</i>	C17	<i>Palaemonetes vulgaris</i>	C64		
<i>Pitar morrhuna</i>	M43	<i>Ampelisca spinipes</i>	C18	<i>Pinnixa sayana</i>	C65	SIPUNCULOIDEA	S1
<i>Pandora gouldiana</i>	M44	<i>Ampelisca spinipes</i>	C19	<i>Petalosarsia declivis</i>	C66		
<i>Retusa canaliculata</i>	M45	<i>Amphithoe valida</i>	C20	<i>Panopeus herbstii</i>	C67	HEMICHORDATA	H1
<i>Retusa obtusa</i>	M46	<i>Amphithoe sp.</i>	C21	<i>Rhithropanopeus harrisi</i>	C68		
<i>Spisula polynyma</i>	M47	<i>Acanthohaustorius millsi</i>	C22	<i>Unciola irrorata</i>	C69	CHORDATA	CH
<i>Spisula solidissima</i>	M48	<i>Calliopius crenulatus</i>	C23	<i>Unciola serrata</i>	C70		
<i>Teledina agilis</i>	M49	<i>Calliopius laevisculus</i>	C24	<i>Trichopoxus epistomus</i>	C71	<i>Molgula citrina</i>	CH1
<i>Teredo navalis</i>	M50	<i>Caprella linearis</i>	C25	<i>Squilla empusa</i>	C72	<i>Molgula manhattensis</i>	CH2
<i>Turbonilla interrupta</i>	M51	<i>Corophium cylindricum</i>	C26	<i>Limulus polyphemus</i>	C73	U/I Chordata	CH3
<i>Tornatina canaliculata</i>	M52	<i>Corophium insidiosum</i>	C27	<i>Edotea montosa</i>	C74		
<i>Rictaxis punctostriatus</i>	M53	<i>Corophium volutator</i>	C28	<i>Diastylis quadrispinosa</i>	C75		
<i>Urosalpinx cinerea</i>	M54	<i>Callinectes sp.</i>	C29	<i>Unciola sp.</i>	C76		
<i>Yoldia limatula</i>	M55	<i>Cancer irroratus</i>	C30	<i>Gammarus sp.</i>	C77		
<i>Yoldia sp.</i>	M56	<i>Cancer borealis</i>	C31	<i>Heteromysis formosa</i>	C78		
U/I Gastropoda	M57	<i>Carcinus maenas</i>	C32	<i>Balanus amphitrite niveus</i>	C79		
<i>Retusa sp.</i>	M58	<i>Crangon septemspinosa</i>	C33	<i>Cyclaspis sp.</i>	C80		
<i>Hydrobia totteni</i>	M59	<i>Ancinus depressus</i>	C34	<i>Unciola inermis</i>	C81		
<i>Cylichna oryza</i>	M60	<i>Dulichia monocantha</i>	C35	<i>Crangonyx sp.</i>	C82		
<i>Nucula annulata</i>	M61	<i>Erichthonius brasiliensis</i>	C36	U/I Mysid	C83		
<i>Bivalve sp. A</i>	M62	<i>Eurypanopeus depressus</i>	C37	<i>Phoxocephalus holbolli</i>	C84		
<i>Turbonilla elegantula</i>	M63	<i>Gammarus annulatus</i>	C38	<i>Paraphoxus spinosus</i>	C85		
<i>Ostomia barttschi</i>	M64	<i>Gammarus locusta</i>	C39	<i>Mysis sp.</i>	C86		
<i>Sayella fusca</i>	M65	<i>Gammarus mucronatus</i>	C40	Cumacea	C87		
<i>Crepidula sp.</i>	M66	<i>Gammarus lawrencianus</i>	C41	<i>Erichsoniella sp.</i>	C88		
U/I Nudibranch	M67	<i>Gammarus fasciatus</i>	C42	Isopoda	C89		
U/I Bivalve	M68	<i>Homarus americanus</i>	C43	Caprellidae	C90		
<i>Tellina sp.</i>	M69	<i>Hyale nilsoni</i>	C44	Hyperidae	C91		
<i>Solen viridis</i>	M70	<i>Ischyrocerus anguipes</i>	C45	<i>Microdeutopus anomalous</i>	C92		
			C46	U/I Amphipoda	C93		
			C47	<i>Upogebia affinis</i>			

as *Pholas*, *Barnea* or *Cyrtopleura*, was listed as *Cyrtopleura*. None of the identification inconsistencies affected the analyses reported here.

The master list of approximately 300 taxa is large for what has been shown in previous reports to be a severely impacted estuarine system. Studies in comparable estuaries have rarely reported such a large inventory. In a study of Raritan Bay-Lower New York Harbor, McGrath (1974) reported only 47 species over a much larger and more varied area, though over a considerably shorter period. In the same New York estuary, Dean (1976) reported only 127 species in a program encompassing four years of intensive sampling. Sanders (1956) in a study in central Long Island Sound, identified only 119 species and McGrath et al. (1978), working in a nearby Connecticut estuary, found 68 species. Although this program was not carried through a full seasonal cycle, the samples represented a very wide variety of habitats.

The New Haven Harbor benthic sampling program was more intensive and extended over a greater number of years than the studies cited. Many of the New Haven Harbor species encountered were seen very rarely and in small numbers. These rare species cannot be considered representative of the area. In addition, many of the species were present only as juveniles and the number of species that develop persistent adult populations is small. The magnitude of the total species list should not be considered indicative of a healthy estuarine benthic habitat.

The importance of immature or transient species in the species list may be seen by noting that the abridged species list (Table 6-3), which comprises only those species occurring in one or more percent of the combined replicate samples over all years, includes only 50 species. This figure is probably more representative of the actual species richness present in the harbor. The abridged list contains a good representation of opportunistic, or pioneering, organisms which tend to dominate in a strongly physically-controlled environment where periodic mortalities create a continual disclimax community. Such species as

TABLE 6-3. ABRIDGED BENTHIC SPECIES LIST*. NEW HAVEN HARBOR ECOLOGICAL SUMMARY REPORT, 1979.

<u>Code</u>		<u>Code</u>	
R	<i>Rhyncocoela</i>	M14	<i>Ensis directus</i>
A2	<i>Capitella capitata</i>	M15	<i>Gemma gemma</i>
A10	<i>Eteone</i> sp.	M17	<i>Hiatella striata</i>
A13	<i>Eumida sanguinea</i>	M18	<i>Ilyanassa obsoleta</i>
A17	<i>Glycera americana</i>	M24	<i>Lyonsia hyalina</i>
A21	<i>Hydroides dianthus</i>	M28	<i>Mercenaria mercenaria</i>
A23	<i>Lepidonotus squamatus</i>	M31	<i>Mulinia lateralis</i>
A29	<i>Mediomastus ambiseta</i>	M32	<i>Mya arenaria</i>
A31	<i>Nephtys incisa</i>	M35	<i>Nucula proxima</i>
A33	<i>Nereis succinea</i>	M38	<i>Nassarius trivittatus</i>
A38	<i>Oligochaeta</i>	M46	<i>Retusa canaliculata</i>
A40	<i>Pectinaria gouldii</i>	M50	<i>Tellina agilis</i>
A43	<i>Phyllodoce arenae</i>	M54	<i>Rictaxis punctostriatus</i>
A47	<i>Polydora ligni</i>	M56	<i>Yoldia limatula</i>
A52	<i>Sabella microphthalma</i>	C3	<i>Balanus improvisus</i>
A53	<i>Sabellaria vulgaris</i>	C5	<i>Neomysis americana</i>
A56	<i>Scoloplos fragilis</i>	C16	<i>Ampelisca abdita</i>
A66	<i>Sthenelais boa</i>	C19	<i>Ampithoe valida</i>
A67	<i>Streblospio benedicti</i>	C29	<i>Corophium</i> spp.
A68	<i>Tharyx acutus</i>	C34	<i>Crangon septemspinosus</i>
A75	<i>Eusyllis</i> sp.	C43	<i>Gammarus lawrencianus</i>
A78	<i>Ampharete arctica</i>	C54	<i>Microdeutopus gryllotalpa</i>
M3	<i>Crepidula fornicata</i>	C56	<i>Neopanope texana</i>
M4	<i>Crepidula plana</i>	C61	<i>Pagurus longicarpus</i>
M11	<i>Anomia simplex</i>	C69	<i>Unciola irrorata</i>

*

Species present in one or more percent of all replicate samples

Streblospio benedicti and *Capitella capitata* are generally recognized as belonging to this group (Fisher and McCall, 1973) and have even been categorized by some authors as "pollution-indicators" (Dean, 1970; Pearson and Rosenberg, 1978; Reish, 1961 and Wass, 1967), although the severe physical stresses that favor their presence need not be pollution related.

Some indication of the extent to which an area has been degraded by pollutants is provided through examination of the number of species representing each of the three major benthic groups: polychaetes, molluscs, and crustaceans. Organisms living in an unpolluted habitat generally represent a wide variety of both feeding types and life strategies. As a habitat becomes progressively degraded by pollutants, this trophic and biological variety is reduced. In heavily impacted habitats, organisms which biologically concentrate pollutants such as carnivores or tubicolous filter feeders tend to be eliminated leaving primarily surface deposit feeders. Reish (1972), gives examples showing that impacted areas are usually dominated by near-surface deposit feeding polychaetes and that filter feeding molluscs and crustaceans are reduced. This overall result can be used to evaluate, strictly, on a comparative basis, the polychaete : mollusc : crustacean species ratio of New Haven Harbor.

The combined New Haven species list contains a polychaete : mollusc : crustacean species ratio of 1.2 : 0.8 : 1.0, which is not indicative of a strongly stressed area. The P : M : C ratio for the more characteristic abridged list, however, is 1.2 : 1.0 : 0.7 which shows a decrease in richness of crustaceans. For comparison, the ratios for the two Raritan Bay studies were 1.6 : 0.6 : 0.8 (McGrath, 1974) and 1.3 : 1.0 : 0.8 (Dean, 1976). Although the decrease in crustaceans is seen in only one of the two studies, the relative increase in polychaetes is obvious. In Clinton Harbor, a relatively pristine Connecticut estuary, the ratio was 1.0 : 0.8 : 1.2, indicating that, under

limited stress in an otherwise similar estuary, crustaceans are well represented.

Based upon the raw frequency-of-occurrence data and the species groups generated by the classification analysis, a group of species considered to be characteristic of the benthic infauna of New Haven Harbor was developed (Table 6-4). In order to qualify for inclusion, a species had to be either ubiquitous or dominant. A ubiquitous species was considered to be any species present at 20 or more of the 26 stations at some time over the four years of the combined programs. Dominant species were those which were among the top five at a station in terms of frequency of occurrence.

In most cases, species which were ubiquitous were also dominant at one or more stations. Every species which was important to the determination of station groupings also qualified as ubiquitous. This indicates that, in this study, the abundance data of the particular component species were critical to the identification of station clusters: presence/absence data would not have allowed detection of the clusters. The fact that only 14 species qualified as either ubiquitous or dominant is further support for how unrepresentative most of the species were.

Frequencies of occurrence based on all samples from a particular station are plotted on charts of New Haven Harbor for 10 of the 4 ubiquitous species identified above (Figures 6-2 and 6-3). *Crangon septemspinosa*, and *Neomysis americana*, *Nucula proxima* and *Pagurus longicarpus* are not shown because of their consistently low frequency of occurrence. Several distinct distribution patterns in the harbor can be seen from these time-averaged distributions. Among the polychaetes, the dominant and widespread group in all areas of the harbor, *Nereis succinea* and *Streblospio benedicti* were most ubiquitous (Figure 6-2). *Nereis* was most common at inner harbor stations 6 and 10, where it occurred in 69% and 81% of all samples, respectively, and was also abundant in the coarser-grained Morris Cove samples where it was present in more than

(Text continued on page 6-21)

TABLE 6-4. DISTRIBUTION OF NEW HAVEN HARBOR CHARACTERISTIC BENTHIC SPECIES AMONG STATION GROUPS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

SPECIES	STATION GROUP [*]			
	1	2	3	4
<i>Glycera americana</i>		C	C	
<i>Nephtys incisa</i>			C	C
<i>Nereis succinea</i>	C	C		C
<i>Polydora ligni</i>				
<i>Streblospio benedicti</i>	D	C		C
<i>Oligochaeta</i>				
<i>Gemma gemma</i>	D			
<i>Tellina agilis</i>		C	C	
<i>Nucula proxima</i>			C	
<i>Mulinia lateralis</i>			C	
<i>Nassarius trivittatus</i>				
<i>Neomysis americana</i>				
<i>Crangon septemspinosa</i>	D			
<i>Pagurus longicarpus</i>		D		

C = characteristic of station group -- present in at least 50% of samples from all stations in the group

D = dominant for station group -- among the five most abundant species in the station group.

*1 = Inner Harbor

2 = Morris Cove shallow water

3 = Morris Cove deep water

4 = Stations 8N, 13N

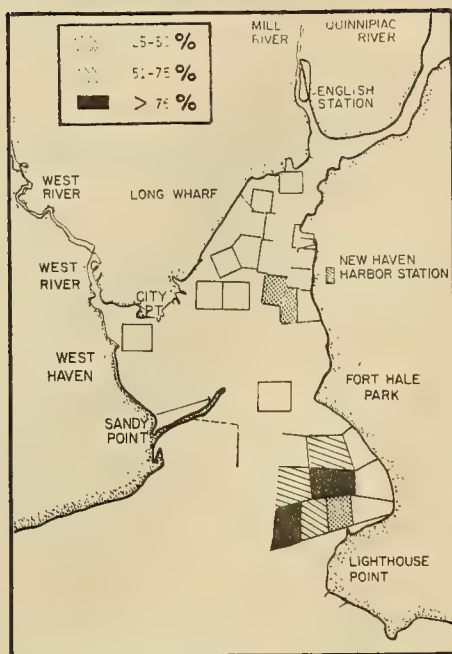
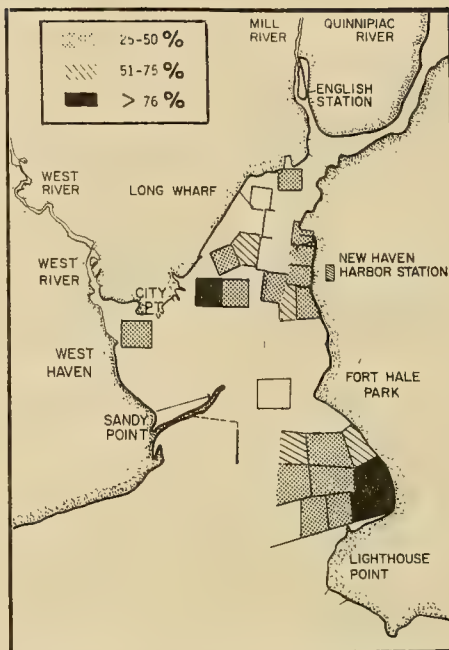
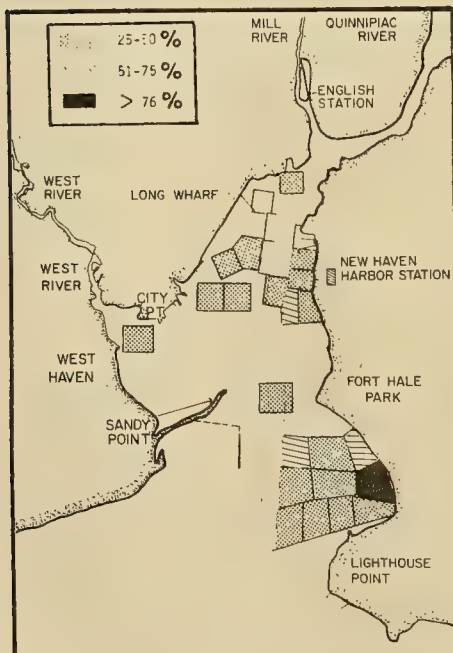
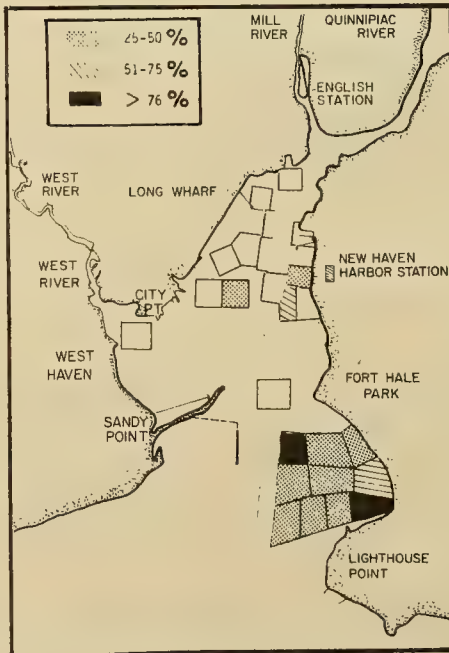
Nephtys incisa*Nereis succinea**Streblospio benedicti**Glycera americana*

Figure 6-2. Spatial distribution of New Haven Harbor characteristic benthic Annelid species with frequency of occurrence values. New Haven Harbor Ecological Study Summary Report, 1979.

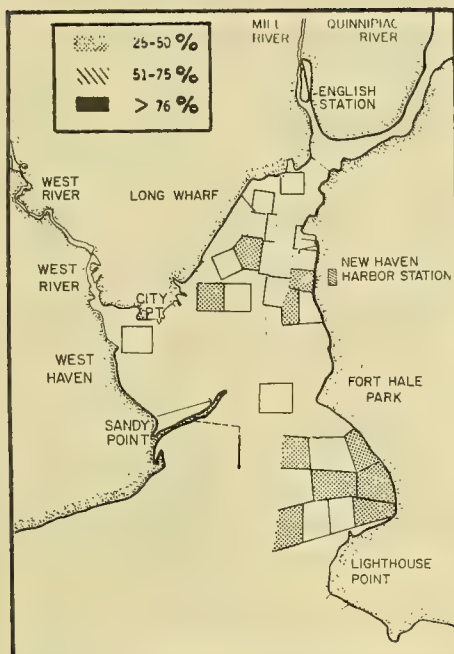
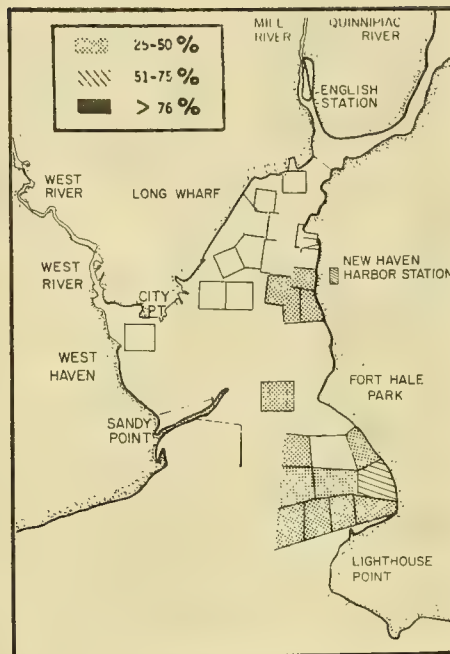
Polydora ligni*Oligochaeta*

Figure 6-2. (Continued)

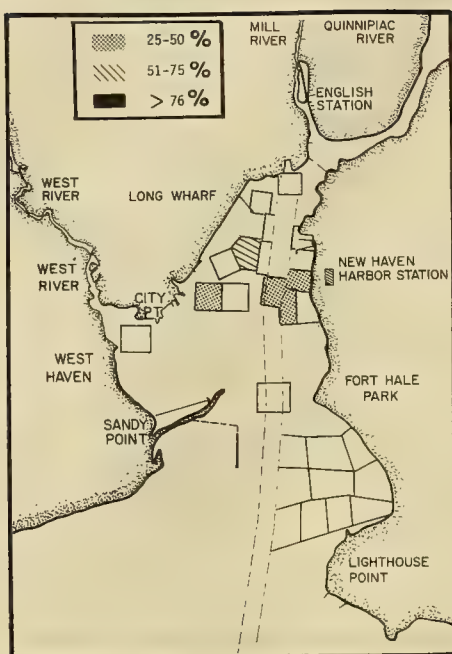
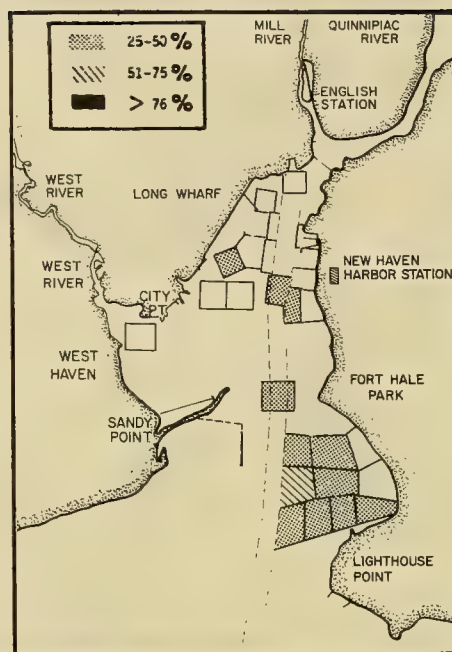
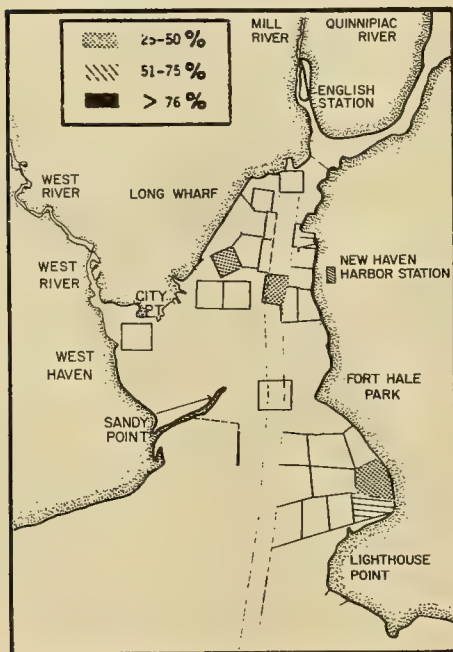
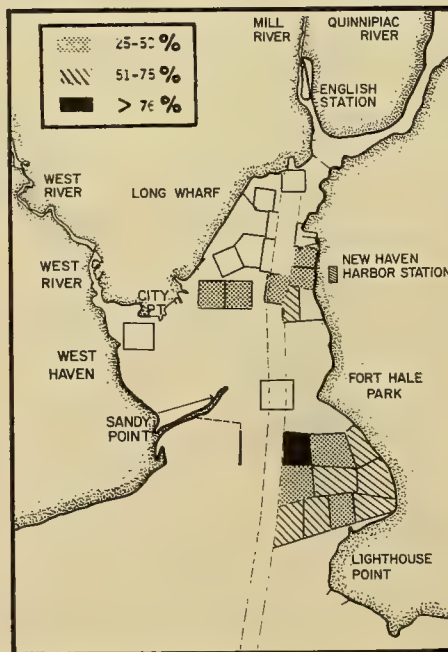
Gemma gemma*Mulinia lateralis**Nassarius trivittatus**Tellina agilis*

Figure 6-3. Spatial distribution of New Haven Harbor characteristic benthic mollusc species with frequency of occurrence values. New Haven Harbor Ecological Study Summary Report, 1979.

50% of all samples from Stations A, C, D and G. These four stations, forming an arc around the northern and western periphery of the Cove, are characterized by a coarser grained sediment than the deeper areas of the Cove and, hence, support a different fauna. *Nereis* was present in at least 25% of the samples at nearly all other stations, including those immediately adjacent to the generating station. *Nereis* was numerically abundant through all sampling months and years (Figure 6-4).

The spatial distribution of *Streblospio benedicti*, an opportunistic polychaete found in many polluted estuarine environments, was similar to that of *Nereis* (Figure 6-2). Like *Nereis*, *Streblospio* was present in greater than 25% of the samples from nearly all stations. Although occasionally reaching high densities in the inner harbor, *Streblospio* did not occur at inner harbor stations in the frequencies exhibited by *Nereis*. Except for Station 8, it never was present in more than 50% of the samples from this area. *Streblospio* occurred most frequently in Morris Cove, particularly at the shallower, coarser-grained stations where *Nereis* was also most abundant. *Streblospio* was numerically important in all study years and seasons (Figure 6-4).

Among those species that were present in frequencies greater than 25% at several stations, *Nephtys incisa* exhibited the most discrete spatial distribution (Figure 6-2). *Nephtys* was characteristic only of the deeper areas of the inner harbor, at Stations 8 and 8N, but was present in greatest frequency in the deeper areas of Morris Cove, at all stations except A, C, D and G. This Morris Cove pattern is the opposite of that described above for *Nereis* and *Streblospio*. *Nephtys* was found in low average densities over all seasons through the years of the study (Figure 6-4).

Glycera americana was found at only three inner harbor stations, 4a, 8 and 9, in greater than 25% of all samples (Figure 6-2). In Morris Cove *Glycera* exhibited a distributional pattern similar to *Streblospio* and *Nereis*, reaching greatest frequencies of occurrence at

MOLLUSCS

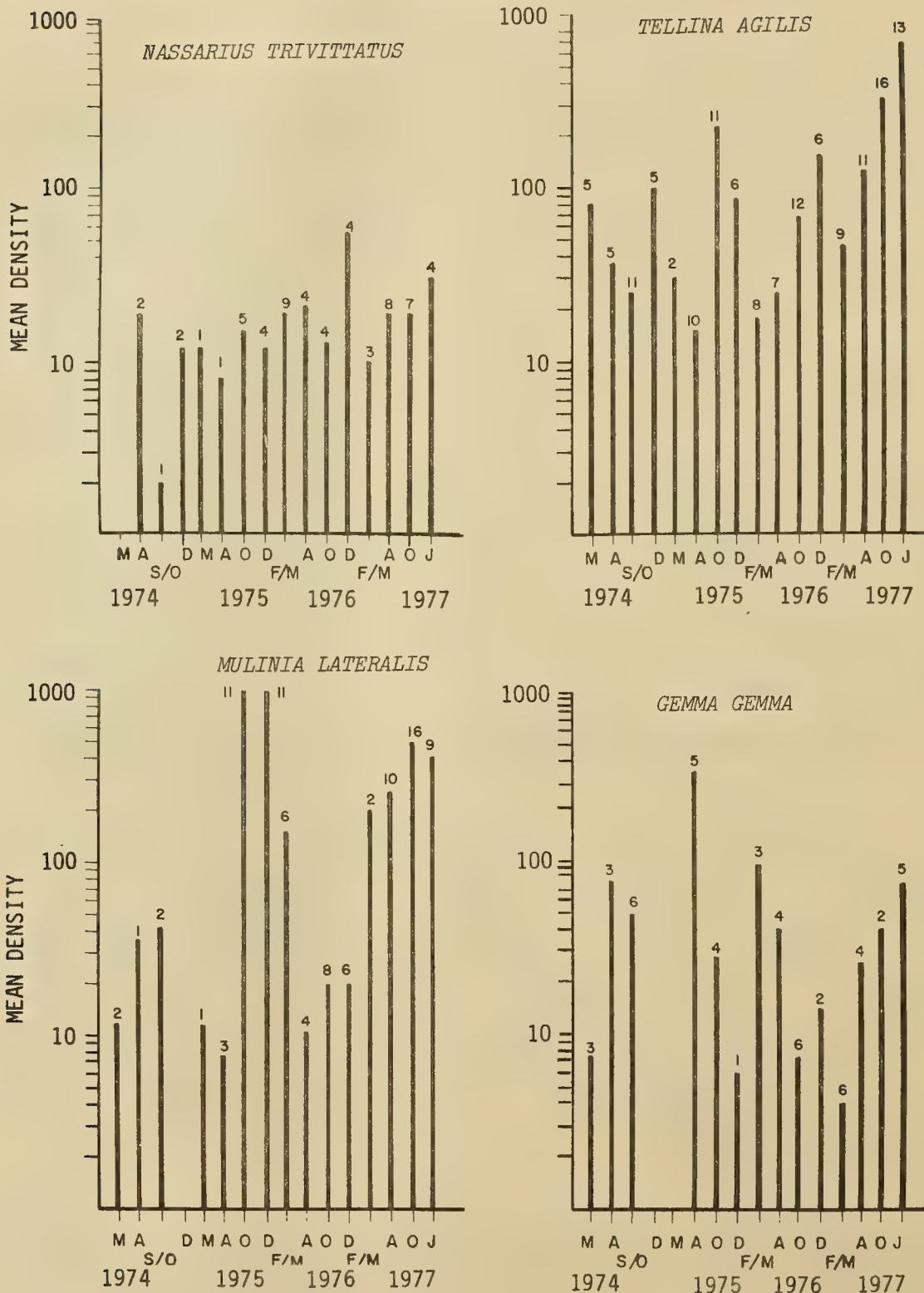


Figure 6-4. Mean densities (individuals/m²) of New Haven Harbor characteristic species (averaged for all samples in which species was present). Number of samples in which species was found is indicated by numeral at top of bar. New Haven Harbor Ecological Study Summary Report, 1979.

Continued

ANNELIDS

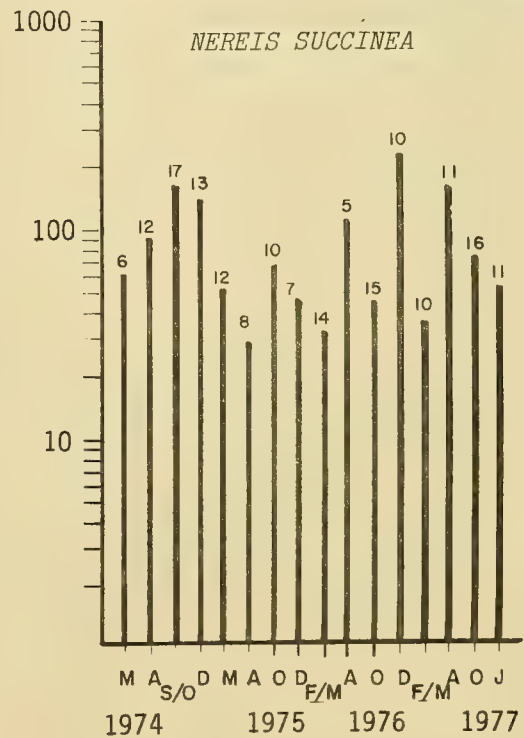
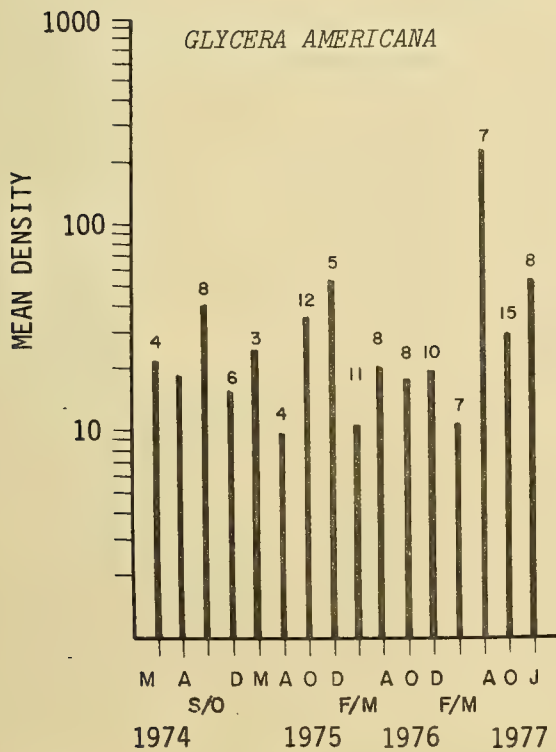
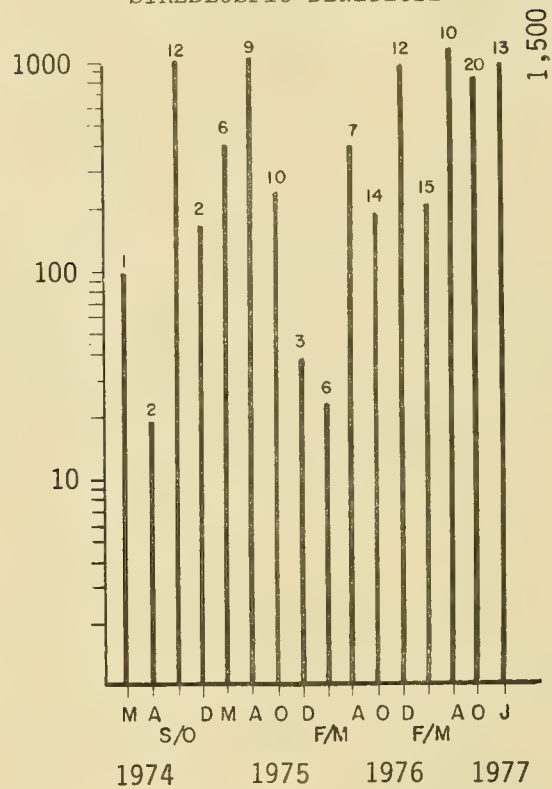
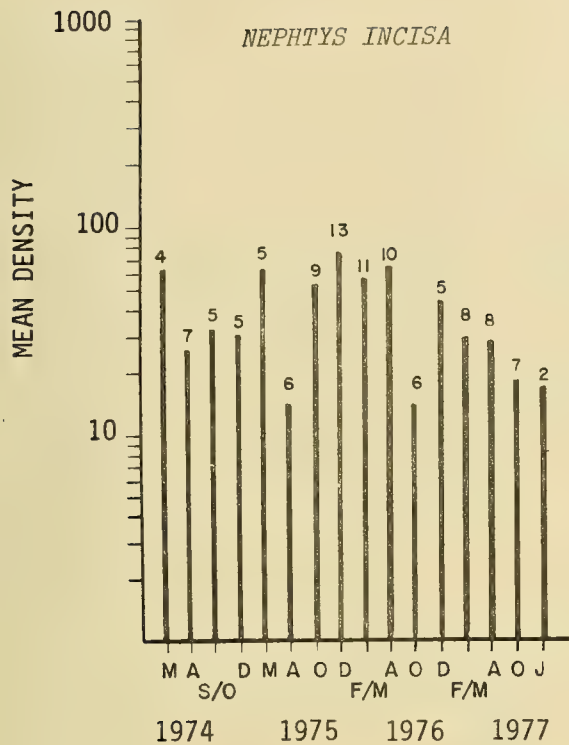
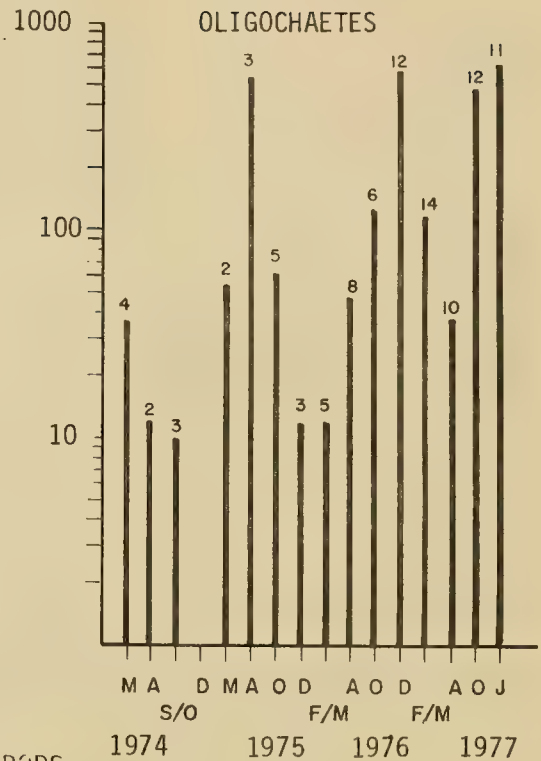
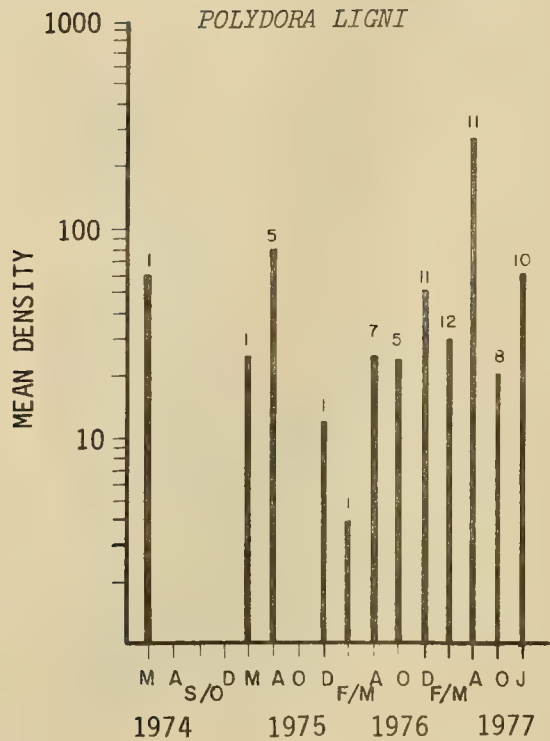
STREBLOSPIO BENEDICTI

Figure 6-4. (Continued)

Continued

ANNELIDS



ARTHROPODS

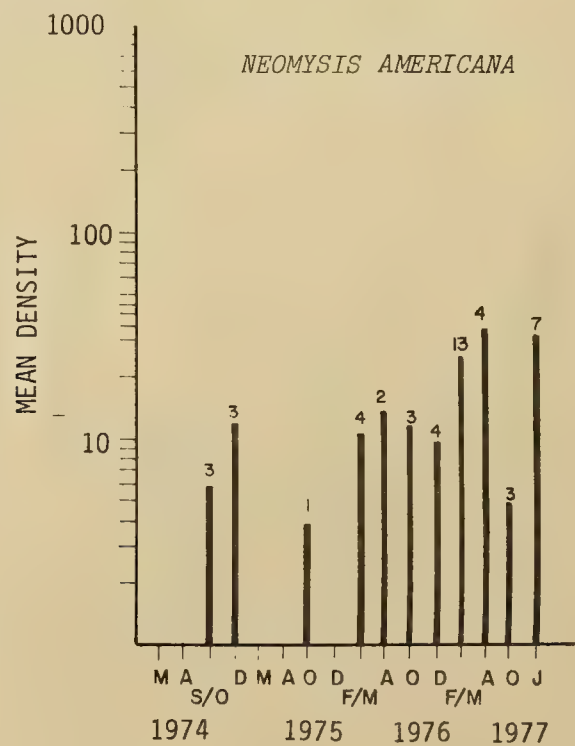
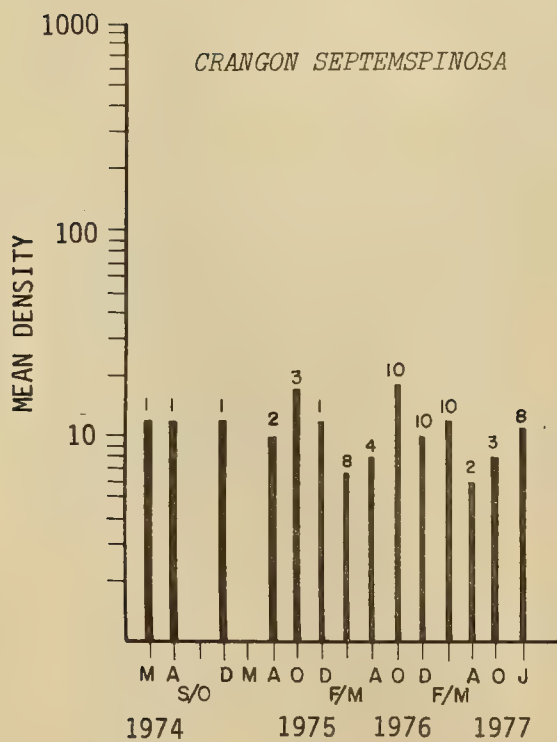


Figure 6-4. (Continued)

nearshore coarse-grained stations, particularly Stations C and G. There was no apparent seasonal or annual variation observed in *Glycera* densities (Figure 6-4).

The remaining ubiquitous polychaete, *Polydora ligni*, did not occur with sufficient frequency at any stations to show a clear pattern of distribution and, indeed, was never present in more than 50% of the samples from any single station (Figure 6-2). However, its distribution was generally similar to that of *Glycera* with only scattered occurrences in the inner harbor and more consistent occurrence in Morris Cove, particularly at coarser grained sediment stations. Densities and frequency of station occurrence data show no seasonal patterns, but seem to have increased since August 1976 (Figure 6-4).

Of the four molluscan species included in Figure 6-3, only *Tellina agilis* and *Mulinia lateralis* were present in a sufficient number of samples to allow generalized statements about their patterns of distribution. Both were present in limited numbers in the inner harbor. Both species were often collected at Stations 8 and 8N. *Tellina* also occurred at Stations 4, 4A, 9 and 10 in greater than 25% of the samples while *Mulinia* was also frequently present only at Station 5N. Both bivalve species were collected most often from stations in Morris Cove. *Tellina* was considerably more abundant than *Mulinia*. *Mulinia* was present in over 50% of the samples only at Station F, while *Tellina* was present in greater than half of the samples from nearly all stations in the Cove, reaching its greatest frequency of occurrence (87%) at Station C. This species was least abundant at Station F, where it was present in only 25% of the samples. *Tellina* was generally most abundant in the shallower areas of the cove, where *Mulinia* was least abundant. Densities and station occurrences were variable with some indication of summer/fall recruitment (Figure 6-4). For *Mulinia*, 1975 and 1977 were years of particularly high abundance. For *Tellina*, 1977 was the year of highest density.

The remaining ubiquitous species are generally too sparse to allow detailed analysis of their distributions. Oligochaetes (Figure

6-2) were generally present in low frequencies at Morris Cove stations and, in the inner harbor, were only present in greater than 25% of the samples from a small group of stations. Greatest frequency of occurrence for oligochaetes was at Station D, where they were present in 56% of the samples. *Gemma gemma* reached frequencies of greater than 25% only at four stations in the inner harbor, while *Nassarius trivittatus* was present at low levels at both inner harbor and Morris Cove stations (Figure 6-2). Abundances and station occurrences of oligochaetes and *Gemma* were variable over the study period. *Nassarius* was usually present at low average densities, though at a variable number of stations (Figure 6-4).

Species Richness

The total number of species at a station is often one of the more conservative characteristics of a community and, as such, variations from the norm may serve as an indicator of community stress. This parameter, however, does not necessarily relate to community stability (May, 1973). The total number of species for each station over all samplings is presented in Table 6-5. These values reflect total species present at a station and are not the mean of the replicates. Direct comparisons among data from the three levels of sampling intensity (R&M pre-1975; R&M post-1975; and NAI), are not legitimate.

An interesting and somewhat perplexing phenomenon of the New Haven benthic system is a precipitous drop in species richness and faunal density at certain stations during the peak of the summer. The "August effect" was tentatively first proposed by Rhoads and Michael (1975) and subsequently developed and modified in following reports (Rhoads and Michael, 1977, 1978). The occurrence of this phenomenon is fairly well documented in the R&M data although it is apparently not exhibited at some stations and the actual causes appear to be more complex than first proposed.

TABLE 6-5. TOTAL NUMBER OF SPECIES PER STATION, MAY 1973 - JANUARY 1978.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

STA	MAY 1973	AUG 1973	MAR 1974	MAY 1974	AUG 1974	SEP 1974	OCT 1974	DEC 1974	MAR 1975	JUN 1975	AUG 1975	OCT 1975	DEC 1975	FEB 1976	MAR 1976	JUN 1976	AUG 1976	OCT 1976	DEC 1976	FEB 1977	MAR 1977	JUN 1977	AUG 1977	OCT 1977	JAN 1978	STA
3N	---	---	---	---	---	---				14	3	1		2		3	23	10		6		2	9	6		3N
5N	15	18		0		6				6	12	13		5		2	14	17		11		4	7	7		5N
6N	---	---	---	---	---	---				10	7	3		4		0	8	6		9		4	7	10		6N
8N	5	19		2		11				5	6	10		7		8	10	12		20		5	13	19		8N
11N	---	---	---	---	---	---				8	1	5		2		3	3	12		7		8	12	16		11N
13N	13	34		13		21				14	21	14		14		15	18	3		18		12	15	29		13N
1	---	---	1		0		1	5	2		0	2	0		0		0	0	0				0	6	1	1
2	---	---	0		0		1	1	1		0	1	2		0		0	0	2				1	0	2	2
3			3		1		0	3	0		0	1	2		0		1	0	0				0	1	2	3
4			0		3		6	7	3		5	10	4		12		23	6	0				0	4	1	4
4a			---		---		---	---	---		---	---	---		7		0	11	31				43	27	18	4a
5			0		0		2	0	2		0	1	3		1		0	2	1				0	3	1	5
6			1		9		3	2	5		13	2	7		6		3	5	---				18	4	20	6
7			0		4		7	0	2		3	11	9		1		0	6	4				0	1	0	7
8			0		2		6	6	4		3	9	5		3		1	18	3				25	24	21	8
9			1		5		5	2	1		0	6	1		14		1	9	19				1	4	20	9
10			0		4		5	5	5		10	7	8		2		0	6	18				3	8	5	10
A			0		1		13	9	2		8	0	4		9		2	20	30				37	29	21	A
B			5		3		6	7	3		3	1	9		11		3	8	34				8	11	23	B
C			7		3		7	7	5		2	22	8		8		15	11	13				22	33	35	C
D			11		9		10	9	10		9	8	15		21		20	20	29				34	22	26	D
E			1		0		6	6	7		4	12	10		10		2	2	18				7	14	24	E
F			1		2		11	7	5		2	11	16		7		7	10	8				8	25	28	F
G			5		9		10	0	11		3	18	14		14		15	12	20				30	19	23	G
H			14		2		5	9	6		7	14	14		10		6	6	11				7	27	12	H
I			15		4		5	0	5		5	14	11		14		11	4	9				11	13	14	I

--- = Not sampled

Particularly low summer species richness values during the summer have not generally been observed in the NAI study (Table 6-5). When combined data from both programs are considered, a reoccurring phenomenon of low summer species richness is not apparent (Figure 6-5). Further discussion of this phenomenon, will be included in the section on faunal densities.

In addition to the lack of support for a general August effect, Figure 6-5 shows that throughout the study, the mean number of species per station was consistently higher at Morris Cove stations. The general pattern of fluctuations in species richness was similar for both areas. Morris Cove supported on the order of 1.5 to 2 times as many species per station as the inner harbor.

Faunal Density

The mean faunal density for each station/sampling period over the entire study is presented in Table 6-6. The high temporal variation in density observed in New Haven Harbor is similar to other benthic habitats which are unable to support a temporally or spatially persistent fauna. The highest densities seen in the data are caused by invasions of *r*-selected opportunistic species that subsequently experience mass mortalities. In turn, other opportunists invade the habitat (McCall, 1977; Rhoads, McCall and Yingst, 1978). This colonization pattern is most evident in the inner harbor, which is subjected to greater environmental stress than Morris Cove. For example, Station 4A experienced a large invasion of *Streblospio benedicti* and oligochaetes between October and December of 1976 increasing the faunal density from 375 to 9333 individuals/m² (Figure 6-4, Table 6-6). These species were entirely absent from the station by March of 1977, apparently because of overwinter mortalities. Station 6 experienced an invasion of *Streblospio* and *Gemma gemma*, a small bivalve, over the summer of 1975, increasing densities by a factor of 10 over five months (2075 to 21888 individuals/m²). This dense population had essentially disappeared by October 1975 when the density had declined to 125 individuals/m².

TABLE 6-6. FAUNAL DENSITY (MEAN INDIVIDUALS/m²) BY STATION, MAY 1973 THROUGH JANUARY 1978. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

STATION	MAY 1973	AUG 1973	MAR 1974	MAY 1974	AUG 1974	SEP-OCT 1974	DEC 1974	MAR 1975	JUN 1975	AUG 1975	OCT 1975	DEC 1975	FEB 1976
1			12		0	12	75	25		0	25	88	
2			0		0	12	0	12		0	12	112	
3			50		12	0	412	0		0	12	50	
4			0		62	625	725	338		62	288	375	
4a			NS		NS	NS	NS	NS		NS	NS	NS	
5			0		0	338	338	150		0	100	50	
6			25		1,325	1,912	125	2,075		21,888	125	288	
7			12		188	350	350	88		788	2,062	312	
8			0		62	225	225	138		188	912	75	
9			12		200	88	88	25		512	1,212	12	
10			0		412	688	688	7,238		325	462	225	
A			288		50	1,375	600	38		200	0	88	
B			12		100	325	350	150		38	12	2,650	
C			238		38	412	112	100		50	3,250	412	
D			650		638	412	650	362		3,088	488	1,112	
E			75		NS	312	7,900	1,000		50	5,988	1,312	
F			50		350	1,168	750	250		88	10,912	10,788	
G			188		275	3,112	NS	2,538		50	3,738	475	
H			300		50	1,670	3,938	4,088		125	6,762	2,150	
I			550		162	1,888	538	1,362		112	4,675	7,762	
3N									1,131	40	20		15
5N	157	7,396		8		554			105	1,187	403		72
6N									1,341	431	44		19
8N	15	3,019		76		4,231			370	40	117		72
11N									89	4	411		87
13N	88	2,145		214		3,858			692	378	2,971		189

STATION	MAR 1976	JUN 1976	AUG 1976	OCT 1976	DEC 1976	FEB 1977	MAR 1977	JUN 1977	AUG 1977	OCT 1977	1978	$\bar{x}$	S
1	0		0	0	0		0		8	208	8	28.8	54.8
2	0		0	0	33		0		8	0	8	12.3	28.0
3	0		8	0	0		0		0	225	58	51.7	111.5
4	2,083		0	1,233	0		0		0	108	8	369.2	574.6
4a	700		1,742	375	9,333		8		21,967	4,267	2,117	5063.6	7472.7
5	8		0	17	17		0		0	25	8	65.7	114.2
6	192		367	100	183		8		1,725	258	1,650	2015.4	5353.6
7	8		0	50	33		8		0	25	0	267.1	524.2
8	25		8	1,698	4,625		1,075		2,567	9,059	5,217	1631.2	2578.5
9	458		8	758	0		0		8	308	5,925	600.9	1460.5
10	42		0	317	1,833		42		175	208	92	796.7	1775.1
A	467		58	1,117	6,825		NS		25,725	2,525	1,358	2714.3	6600.4
B	275		92	392	13,467		792		100	2,683	4,275	1607.1	3402.7
C	142		1,125	617	1,883		2,975		2,892	7,358	10,708	2019.5	3021.7
D	2,283		658	1,883	9,925		4,525		13,367	2,150	3,950	2883.8	3711.0
E	442		75	25	750		675		125	4,142	8,492	2090.9	3000.3
F	342		150	150	208		833		300	5,725	15,258	3043.2	4887.0
G	617		317	783	2,492		10,425		2,758	3,033	5,175	2398.4	2721.5
H	250		300	150	517		500		183	2,892	2,067	1617.0	1945.3
I	1,550		733	150	142		517		225	2,692	6,408	1841.6	2387.3
3N		11	2,684	83		49			143	94		408.1	821.0
5N		19	1,005	423		98			306	4,702		1101.3	2101.8
6N		0	325	238		342			883	355		353.9	416.6
8N		121	193	930		1,517			1,223	1,494		903.4	1262.5
11N		125	68	571		139			132	1,732		322.5	495.9
13N		1,138	635	276		454			2,321	2,260		1353.9	1242.8

NS = Not sampled

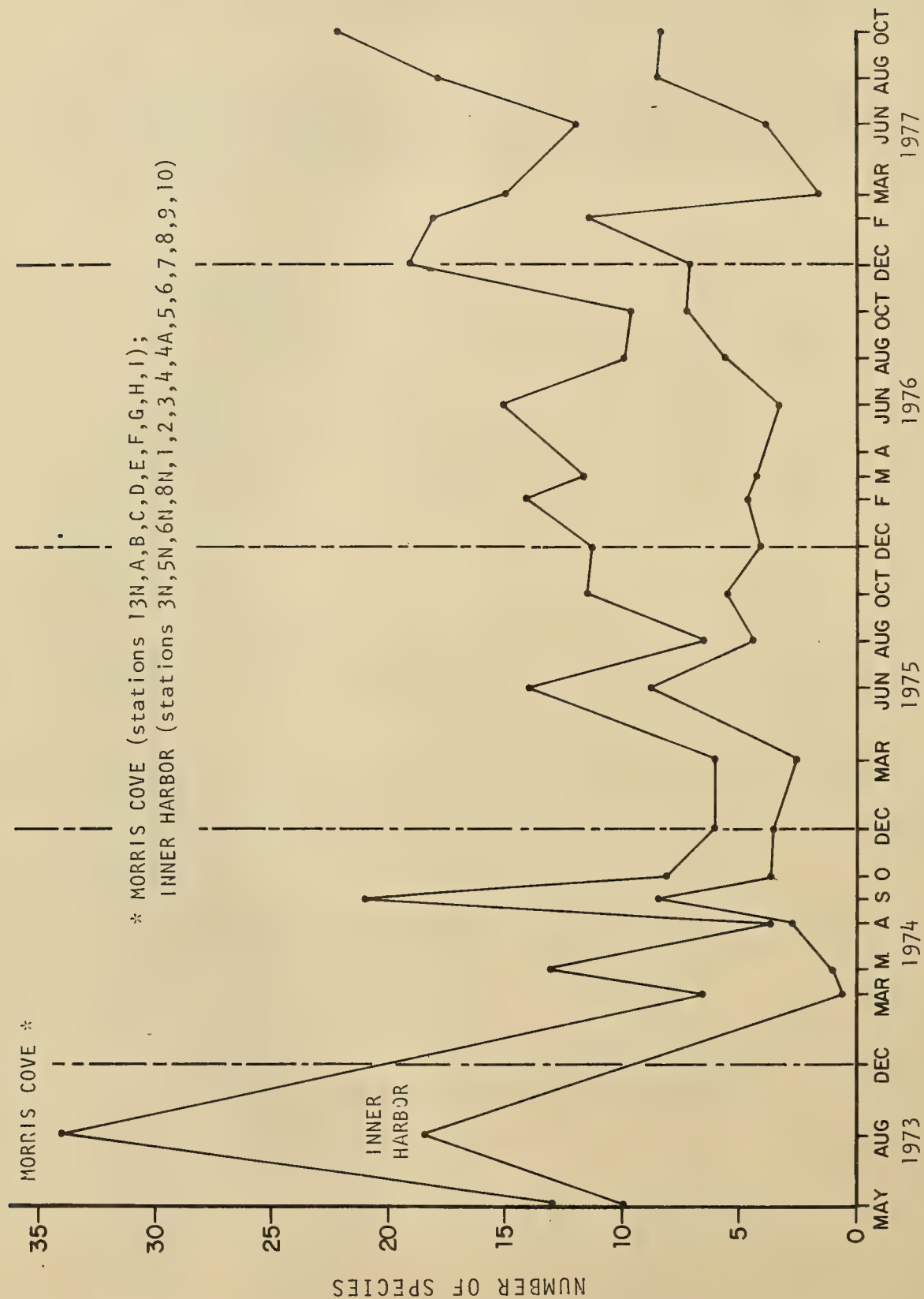


Figure 6-5. Mean total species per station for Morris Cove and Inner Harbor stations, May 1973 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

In addition to these fluctuations there is a seasonal pattern of change in faunal density which has been noted in previous reports. Figure 6-6 shows these density changes at 1) two Morris Cove deep-water (fine sediment) stations, 2) two Morris Cove shallow-water (coarse-grained sediment) stations and 3) two inner harbor deep-water stations, respectively. All three areas exhibit the same general trend. Seasonal density minima tend to occur in late-summer, with the densest populations generally occurring in late fall. This is particularly evident in the inner harbor, although somewhat less clear at the shallow-water Morris Cove stations, and again readily discernible at the deep Morris Cove station although the radical changes in density characteristic of the other areas are not so apparent (Figure 6-6).

The pattern of seasonal density minima occurring in the late-summer is somewhat unusual as most natural benthic populations, if they exhibit pronounced seasonality, tend to develop maximum densities during this period and into the early fall. In an unpolluted bottom area, particularly one exposed to storms, the late fall/early winter period is marked by low densities. The pattern observed in New Haven Harbor tends to confirm the conclusions offered in earlier reports that pollution-related stresses, which are most evident during the summer, are the primary controlling factor for the New Haven benthos. In light of these data on faunal density it is possible to place the hypothesis of an "August effect" in its proper perspective.

From Figure 6-6 we see that Station 5 shows a precipitous decrease in faunal density during August for each of the four years of the program. This pattern is somewhat less evident at Station 10 and at shallow stations in Morris Cove, and quite marked, though without such precipitous declines, in the deeper Morris Cove stations. These observations, combined with the fact that August declines were not apparent at the NAI inner harbor stations tend to indicate that the occurrence of dramatic faunal declines in August depends upon station location and water depth. Dissolved oxygen data (Normandeau Associates, Inc., 1975-1978) indicate that dissolved oxygen values generally decrease with

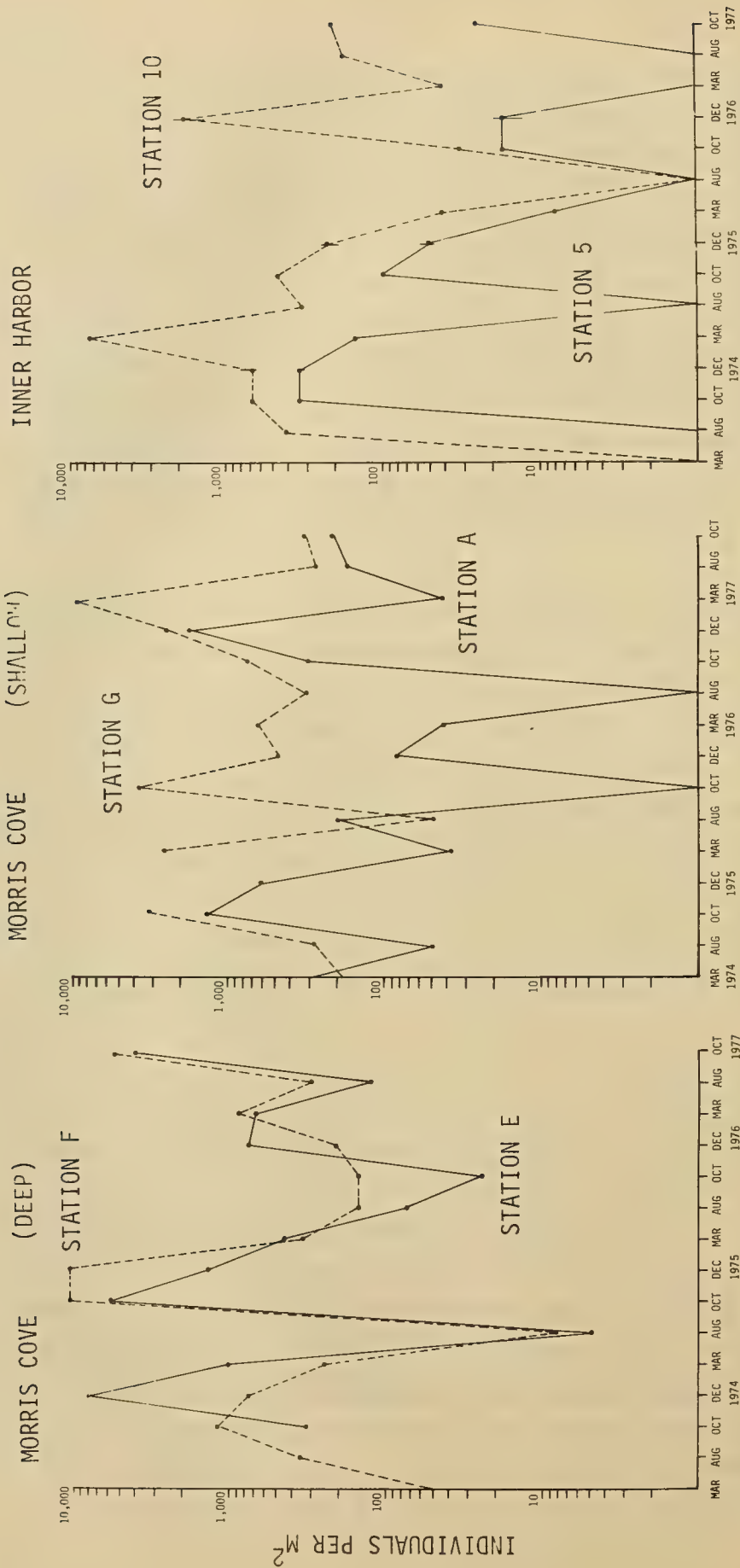


Figure 6-6. Faunal densities (individuals/m²) for Morris Cove deep water (Stations E,F); Morris Cove shallow water (Stations A,G) and Inner Harbor (Stations 5, 10). New Haven Harbor Ecological Studies Summary Report, 1979.

depth and are at seasonal minima in the inner harbor during summer months. Three of the NAI inner harbor stations are located in shallow areas where the decreasing oxygen concentration with depth is not as important a factor. The other two NAI stations are located in channels, where periodic ship traffic may contribute to the mixing and aeration of bottom water and where saline and comparatively oxygen-rich water from Long Island Sound moves up-harbor along the bottom.

An additional factor in the August population decline appears to be associated substratum type, which is a function of local hydrographic conditions and dredging history. Coarse-grained substrata, in addition to containing lower levels of heavy metal ions, are indicative of bottom scour by water movement which also tends to produce vertical mixing and locally elevated dissolved oxygen values. The effect of substratum in limiting the August mortalities may be seen at Station 8. Prior to August 1977 this station consisted of organic-rich mud and showed an August effect. During 1978, after the station substrate had been changed to gravel probably by current changes resulting from dredging activity, August mortalities did not occur. In addition, Station 4A, a sand-gravel substratum station located in shallow water on a pile of dredged material in the inner harbor reached some of its highest densities in August.

The August mortalities were most pronounced when the three factors (location in the inner harbor, deep-water, and muddy substrata), occur together. These factors characterize most of the R & M inner harbor stations. Non-coincidence of the factors results in an unclear pattern of seasonality as seen in the shallow water Morris Cove stations. A combination of deep-water and muddy substrata seems to have produced a degree of stress during August which was sufficient to produce the characteristic seasonal pattern but without the catastrophic population decreases observed in the inner harbor (Figure 6-6).

One additional feature of Figure 6-6 is that Morris Cove stations generally exhibited greater faunal densities than the inner harbor stations and were only rarely devoid of benthic macrofauna. The deeper Morris Cove stations showed considerable persistence and predictability

as compared with the other two areas. This is probably related to the combined factor of reduced pollution stress and increased physical stability of the substratum.

Diversity

Information-theory diversity values (Shannon-Weaver Diversity, Brillouin Diversity, Evenness, $H'_{\max}$ and $H'_{\min}$) for all samples are presented in Appendix 1. The extreme variability of these parameters in New Haven Harbor is apparent. Often the variability among replicates is as great as the range of variability seen over an entire sampling period. Although there have been several attempts to relate absolute diversity values to some observed or measured level of pollution-induced stress, the applicability of diversity values as absolute indices of environmental degradation has largely been dismissed. The consideration of diversity indices in the New Haven Harbor program is generally restricted to spatial and temporal comparisons of patterns of faunal richness and abundance.

Some patterns in the distribution of diversity values within the harbor can be identified, however, even with the high within-station variability. Brillouin diversity frequency distributions (H'_b) for individual replicates from the R&M study are presented as histograms by sampling period in Figure 6-7. Morris Cove and inner harbor stations are presented as separate groupings and a third histogram combining all samples is also included. Examination of these histograms establishes a pattern of diversity in the harbor which is consistent with our earlier observations of species richness and density.

Morris Cove stations demonstrate a consistently higher range of diversity values than inner harbor stations. In 1974, for example, inner harbor diversities, rarely exceeded a value of 1.5. At Morris Cove in 1974, values were frequently greater than 1.5, and often exceeded 2.0 even during March, the sampling period with the lowest mean diver-

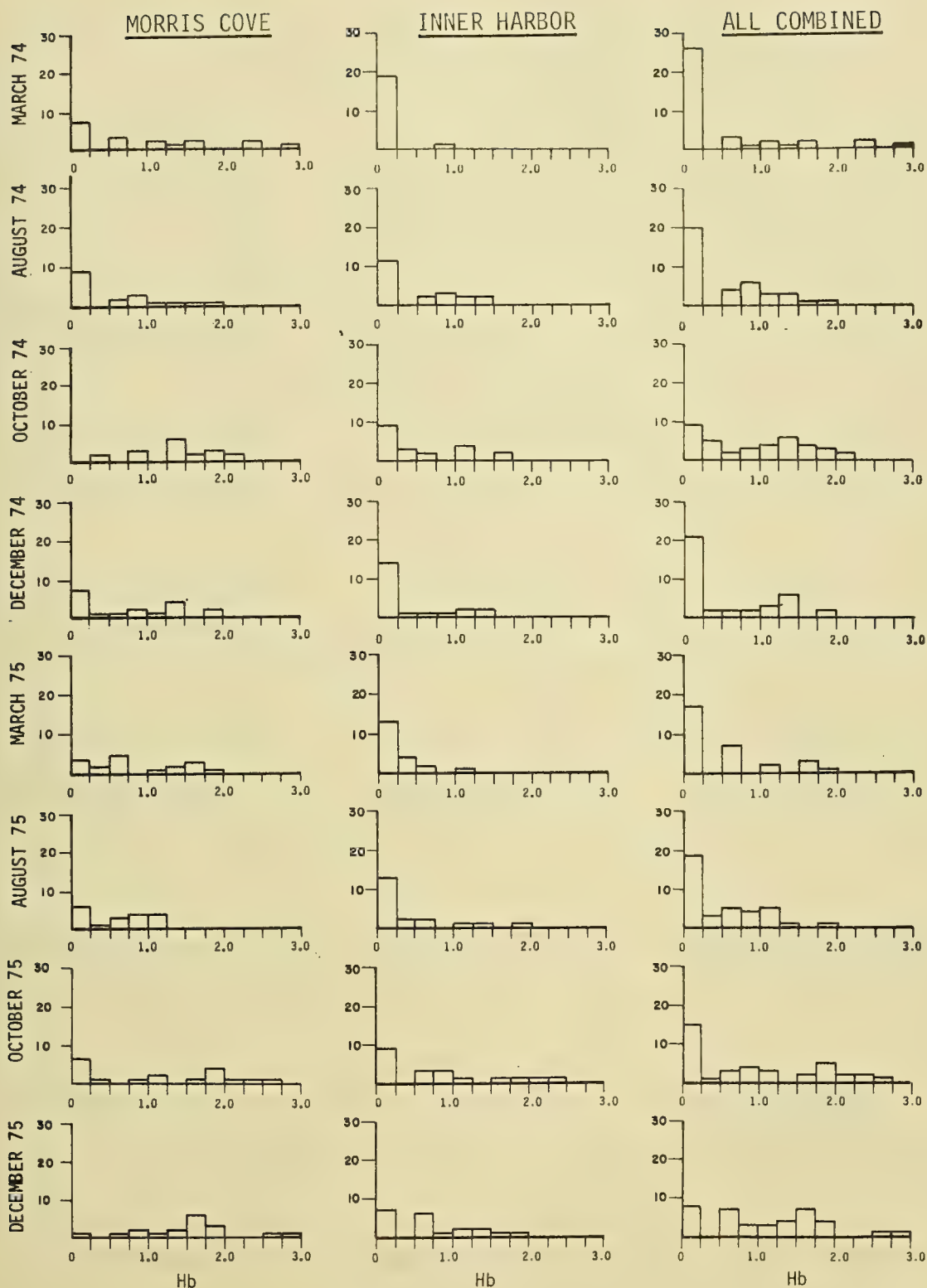


Figure 6-7. Brillouin diversity (H_b) histograms for Morris Cove, Inner Harbor and combined data (R & M data only). New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

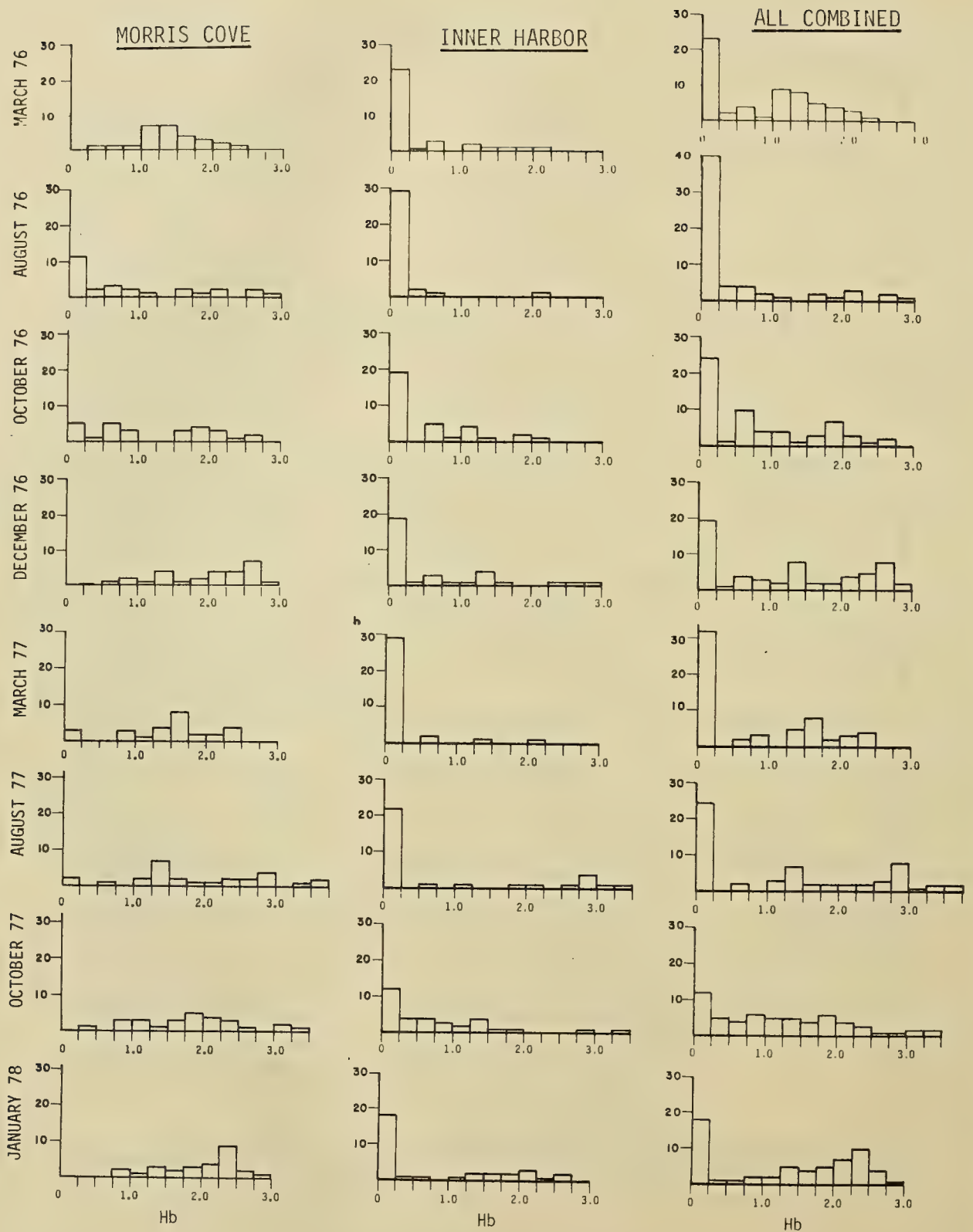


Figure 6-7. (Continued)

sity. Due to the degree of variability in the data it is difficult to detect a true seasonal trend of diversity; however, in 1974, 1975 and 1977 diversities in Morris Cove reached their greatest values in October or December. This type of seasonal trend is common in natural communities as spring recruitment commencing during spring months extends into the summer and fall increasing species richness and density. A slight trend of annually increasing values was also apparent at Morris Cove. The inner harbor diversities were lower and less consistent than those at Morris Cove. The trend of higher late fall values was noted in October 1974 and 1975 but was obscure for other years. The greater variation and lower diversities in the inner harbor may be related to the environmental stresses encountered by benthic organisms due to increased pollutant impact in the inner harbor during late summer.

Within-Station Variability

In order to develop an understanding of the variability of three important biological parameters (species richness, density, and diversity), the coefficients of variation (CV) among three replicates for each parameter were calculated for six stations for 1977 (Table 6-7). Stations in Morris Cove were selected at random. This was not considered appropriate for inner harbor stations as, in some cases, there were only three or four stations with any macrofauna. Inner harbor stations with the most animals were selected so that the results might in some way represent the "best" case. One might argue that three replicate samples containing no macrofauna show low variance, but we cannot be sure that there were no animals adjacent to the sampling area.

The mean CV values for the three parameters are presented for the inner harbor and Morris Cove samples separately in Table 6-8. The CV for these parameters range from 20.7 to 74.0% of the mean. The number of individuals in a sample is the most variable of the three. Diversity, which is effectively limited to a range of 0.0 to approximately 4.0, was the most stable parameter among replicates with a CV of

TABLE 6-7. COEFFICIENT OF VARIATION (CV) (% OF MEAN) VALUES FOR NUMBER OF SPECIES, NUMBER OF INDIVIDUALS AND DIVERSITY, 1977, BASED ON 3 REPLICATE SAMPLES. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

MONTH	STATION	# SPECIES 1977	# INDIVIDUALS 1977	DIVERSITY 1977
March	6	175.0	175.0	*
	7	175.0	175.0	*
	10	86.0	171.0	87.0
	B	51.0	67.0	21.0
	D	28.0	39.0	20.0
	I	33.0	28.0	24.0
August	6	48.0	19.0	17.0
	7	18.0	49.0	6.0
	10	50.0	38.0	95.0
	B	33.0	25.0	36.0
	D	40.0	94.0	17.0
	I	44.0	63.0	21.0
October	6	17.0	97.0	40.0
	7	22.0	22.0	37.0
	10	0.0	104.0	7.0
	B	24.0	16.0	8.0
	D	16.0	20.0	6.0
	I	19.0	49.0	52.0
December	6	16.0	55.0	31.0
	7	5.0	20.0	25.0
	10	66.0	33.0	100.0
	B	16.0	61.0	26.0
	D	6.0	27.0	1.0
	I	22.0	8.0	17.0

* Not recorded

TABLE 6-8. COEFFICIENT OF VARIATION (CV) (% OF MEAN) VALUES AVERAGED FOR NEW HAVEN HARBOR, 1977; INNER HARBOR AND MORRIS COVE SITES AND CV VALUES FROM PLYMOUTH, MASSACHUSETTS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	# SPECIES	# INDIVIDUALS	DIVERSITY
New Haven Harbor			
Inner Harbor 1977	47.3	74.0	42.0
Morris Cove 1977	27.6	29.0	20.7
Plymouth, Mass.*			
Depth			
10'	11.8	49.4	27.0
20'	16.3	35.9	23.5

* From Michael *et al.*, 1978.

50% or less of the mean. Variability of species richness was intermediate between the other two parameters.

In all cases, variability between replicates was greater in the inner harbor than in Morris Cove. This is to be expected as even a cursory examination of the raw data reveals greater differences among replicates from the inner harbor than from Morris Cove.

As a comparison, Michael *et al.* (1978), in summarizing the results of a subtidal sampling program at Plymouth, Massachusetts where three replicates were collected, found the variation reported in Table 6-8.

The Plymouth data are from an area that is not subject to pollution stress, although it experiences a fair degree of natural disturbance by wave action. The Morris Cove results are closer to the lower CV values of the Plymouth data, whereas the inner harbor represents a more variable environment with higher CV values.

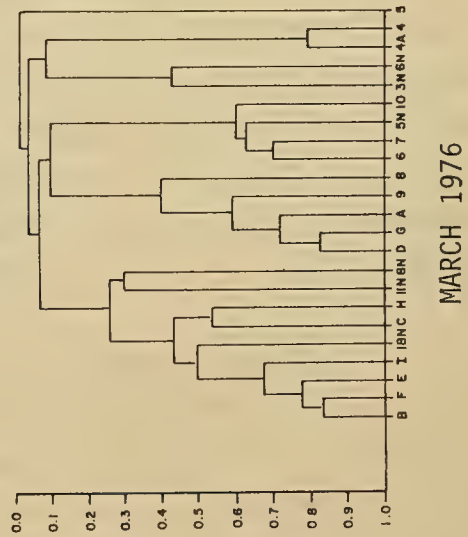
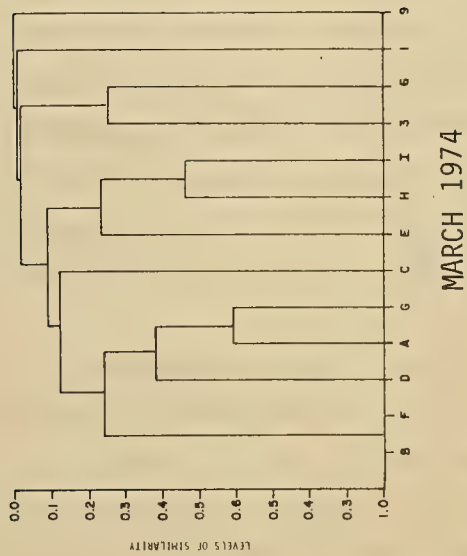
Species which were designated as characteristic were also examined for variability among replicates. Two sampling periods from 1977 were chosen at random and the data from stations that the particular species characterized were tested for variation among replicates. In general the CV for individual characteristic species ranges from 50% to 100% of the mean. This parameter is therefore less predictable than species richness, diversity, or total number of individuals.

Classification Analysis

Results of the cluster analyses are presented as dendrograms in Figure 6-8 and 6-10 and mapped in Figure 6-9. Analysis of the dendrograms by strictly objective methods is difficult because of the temporally and spatially irregular appearances of a number of opportunistic and eurytopic species. Station similarities are inconsistent and generally low. In order to attempt to identify some objective station groupings in the harbor, the normal (Q-type) dendrograms were examined for linkages between stations at a level above 0.5. These were recorded for each sampling period and subsequently arranged in a trellis diagram (not presented) showing number of linkages >0.5 over the entire program for all possible pairs of stations. Because the NAI stations did not occur in all of the dendrograms, the number of such linkages for these stations was increased proportionately. Station-pairs that had four or more pairings >0.5 in common were relatively rare and formed four rather discrete groupings. Their spatial distributions are shown in Figure 6-10. Examination of the inverse (R-type) dendrograms (Figure 6-10) and the species frequency lists, identifies the component species groups which are responsible for the described clusters (Table 6-9).

A three-station cluster comprising Stations 5, 10 and 6N occupies a small band of the inner harbor reaching from City Point to the channel opposite the New Haven Harbor Station (Figure 6-9). This was the only cluster to appear in the inner harbor. The formation of clusters in this type of analysis requires some consistency, or at least congruent variation, in the species composition at the stations in question. This is clearly difficult to find in New Haven inner harbor.

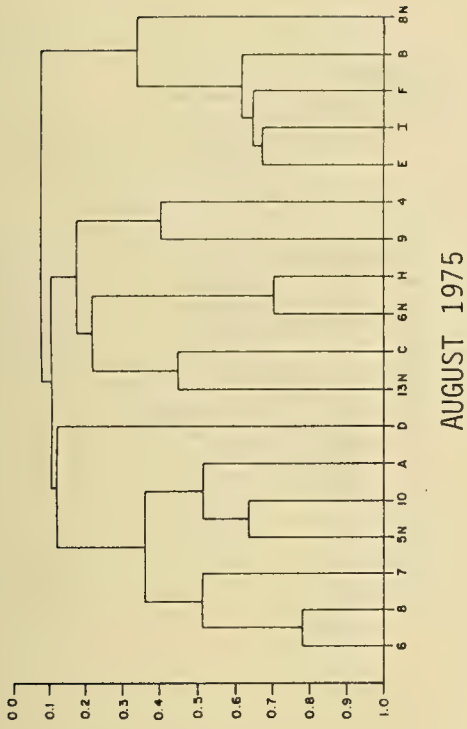
The species which dominates the inner harbor cluster is *Nereis succinea* (Table 6-9). Though nodal analyses are not presented in this report, some results are reported that are useful to provide an objective and simple way to consider the relationships of species and station groupings. Constancy of *Nereis* was high for the inner harbor station group, particularly for Station 10 (i.e., proportion of *Nereis*



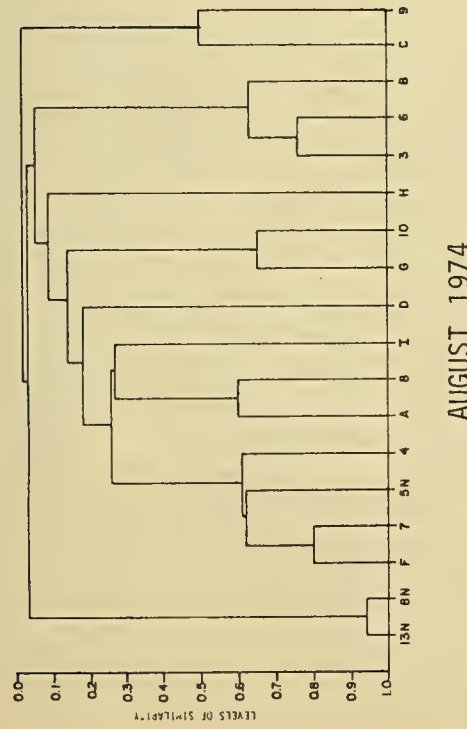
a. March

Figure 6-8. Station grouping dendrograms from normal (Q-mode) cluster analysis, by sampling date. New Haven Harbor Ecological Studies Summary Report, 1979.

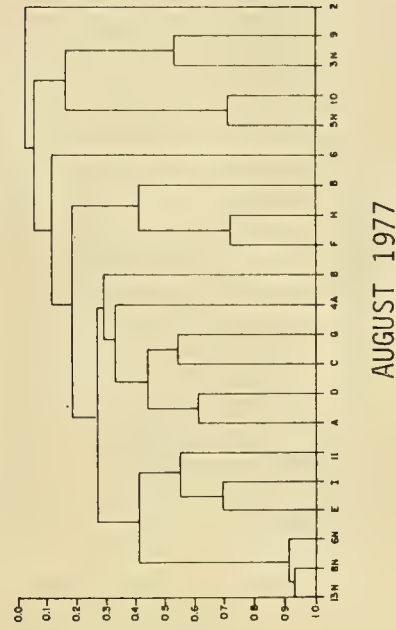
Continued



AUGUST 1975



AUGUST 1974



AUGUST 1977

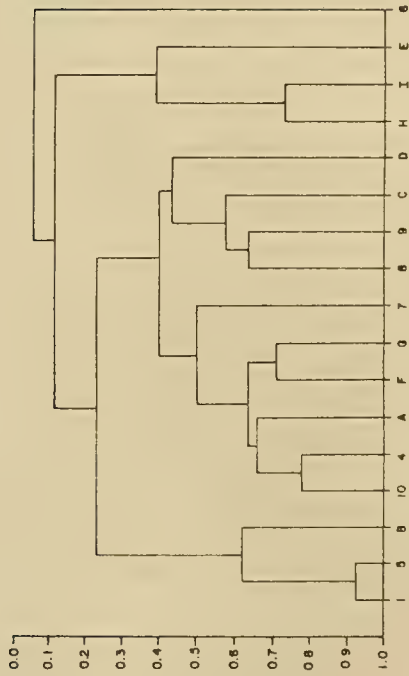


AUGUST 1976

b. August

Figure 6-8. (Continued)

Continued



OCTOBER 1974



OCTOBER 1975



OCTOBER 1976

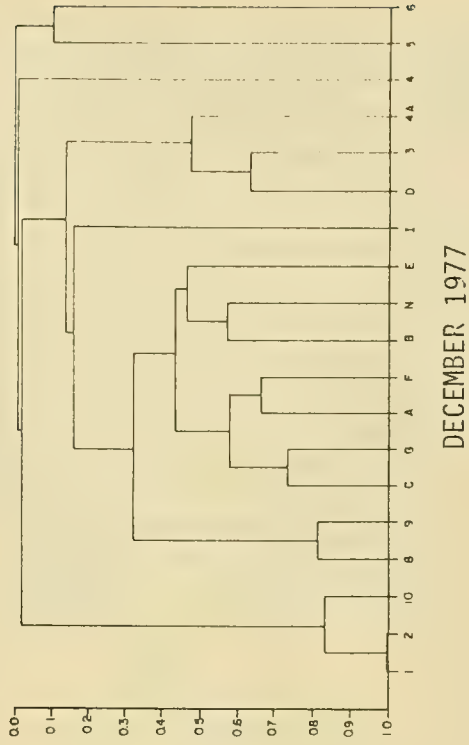


OCTOBER 1977

c. October

Figure 6-8. (Continued)

Continued



d. December

Figure 6-8. (Continued)

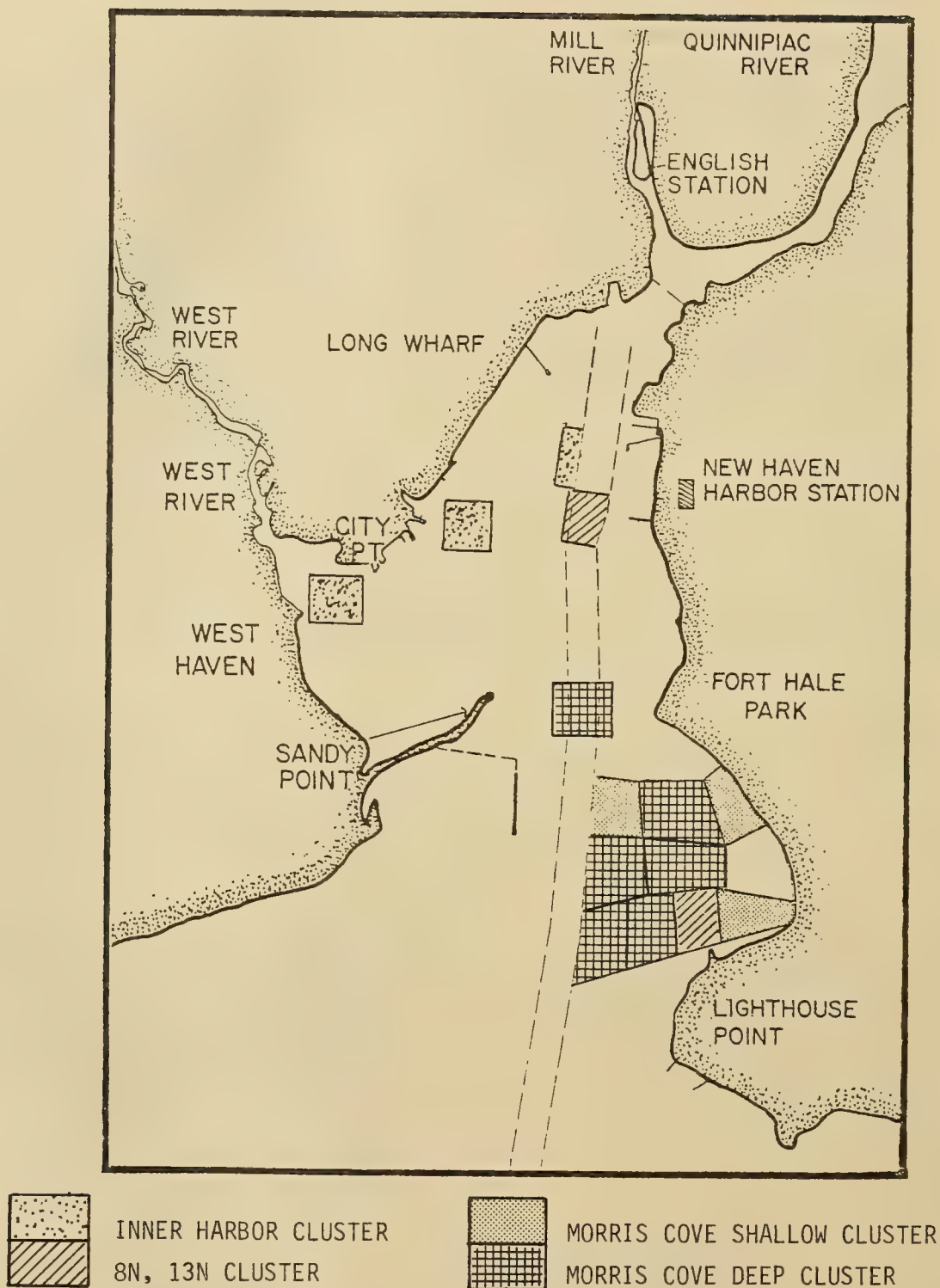


Figure 6-9 . Spatial distribution of station groups * identified from dendrograms (Figure 6-7). New Haven Harbor Ecological Studies Summary Report. 1978.

* Station groups were those determined from Figure 6-7 to have four or more pairings with a similarity of >0.5 .

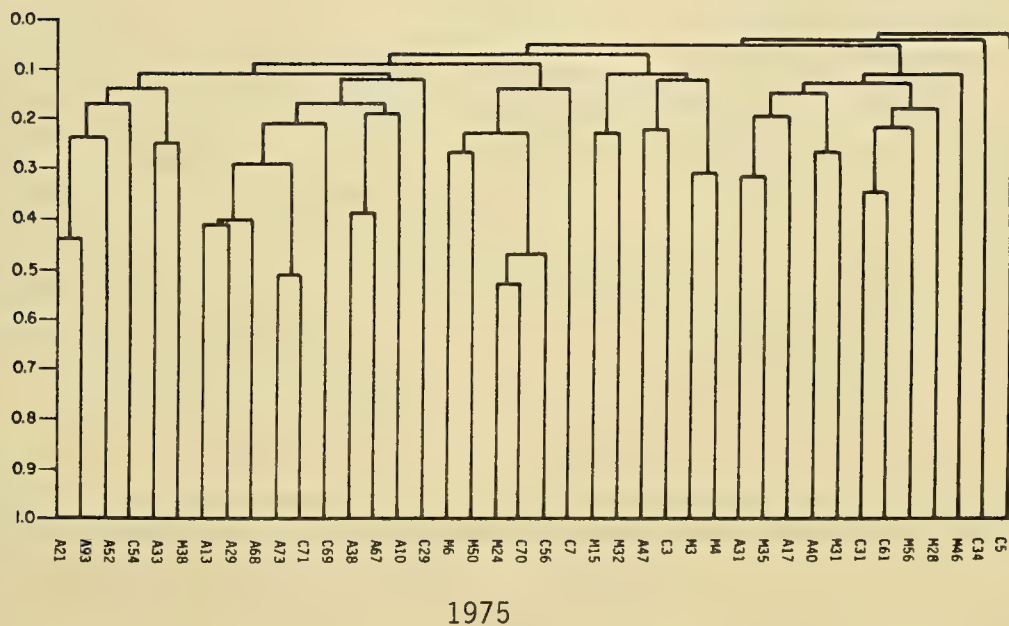
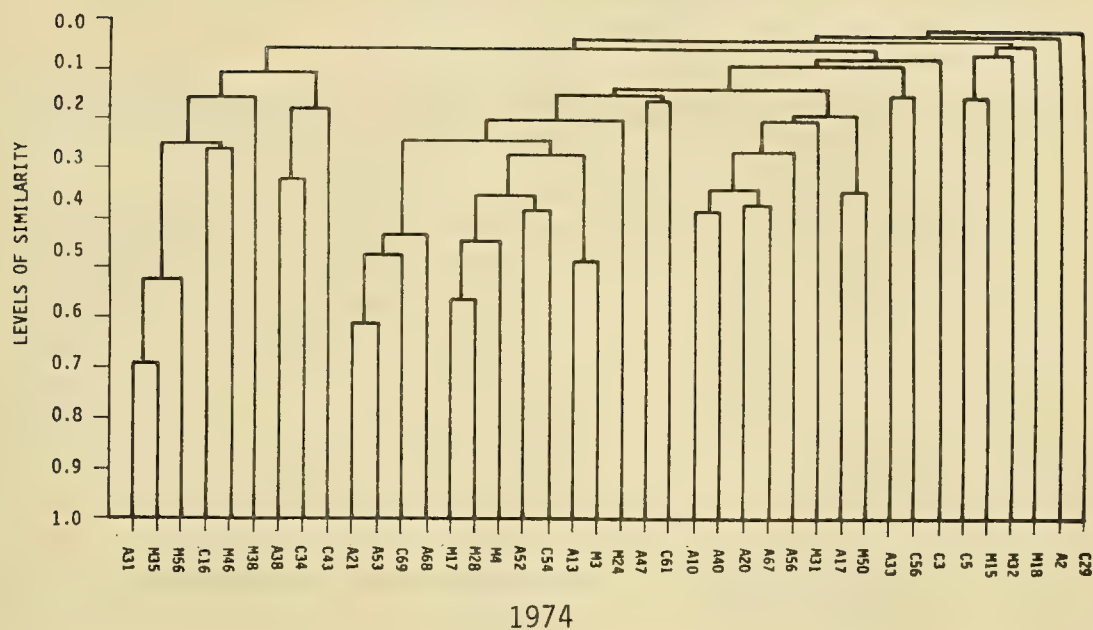


Figure 6-10. Inverse (R-mode) dendrograms from cluster analysis, by year (Refer to Table 6-3 for species codes). New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

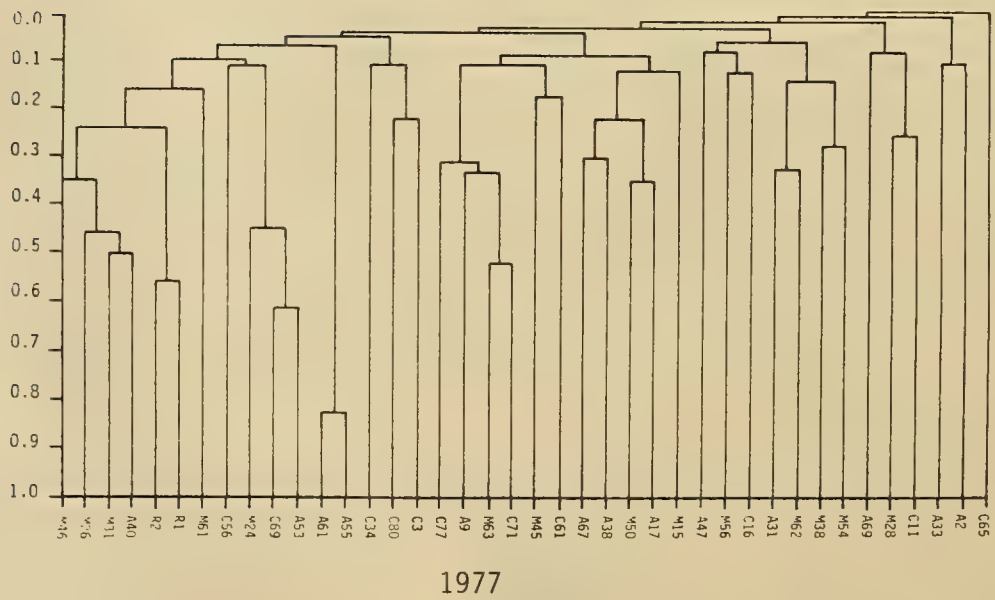
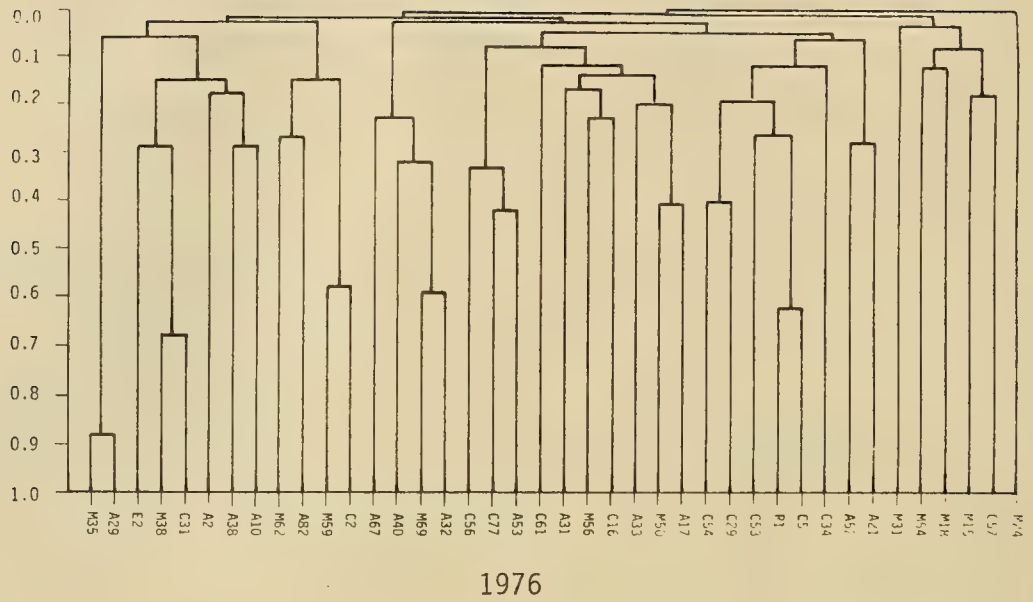


Figure 6-10. (Continued)

TABLE 6-9. BENTHIC SPECIES CHARACTERISTIC OF GROUP STATIONS FOR FOUR STATION GROUPS (RANKED BY FREQUENCY OF OCCURRENCE). NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

INNER HARBOR CLUSTER

<u>STATION 5</u>	<u>STATION 10</u>	<u>STATION 6N</u>
1. <i>Crangon septemspinosa</i>	1. <i>Nereis succinea</i>	1. <i>Nereis succinea</i>
2. <i>Nereis succinea</i>	2. <i>Streblospio benedicti</i>	2. <i>Streblospio benedicti</i>
3. <i>Capitella capitata</i>	3. <i>Gemma gemma</i>	3. <i>Ilyanassa obsoleta</i>
4. <i>Glycera americana</i>	4. <i>Capitella capitata</i>	4. <i>Gemma gemma</i>

MORRIS COVE DEEP CLUSTER

<u>STATION B</u>	<u>STATION E</u>	<u>STATION F</u>
1. <i>Nephtys incisa</i>	1. <i>Nephtys incisa</i>	1. <i>Nephtys incisa</i>
2. <i>Tellina agilis</i>	2. <i>Tellina agilis</i>	2. <i>Nucula proxima</i>
3. <i>Streblospio benedicti</i>	3. <i>Nucula proxima</i>	3. <i>Mulinia lateralis</i>
4. <i>Glycera americana</i>	4. <i>Ampelisca abdita</i>	4. <i>Glycera americana</i>
5. <i>Sabellaria vulgaris</i>	5. <i>Retusa canaliculata</i>	5. <i>Ampelisca abdita</i>

<u>STATION H</u>	<u>STATION I</u>	<u>STATION 11N</u>
1. <i>Nephtys incisa</i>	1. <i>Nephtys incisa</i>	1. <i>Nephtys incisa</i>
2. <i>Tellina agilis</i>	2. <i>Tellina agilis</i>	2. <i>Mulinia lateralis</i>
3. <i>Mulinia lateralis</i>	3. <i>Nucula proxima</i>	3. <i>Streblospio benedicti</i>
4. <i>Glycera americana</i>	4. <i>Mulinia lateralis</i>	4. <i>Oligochaeta</i>
5. <i>Oligochaeta</i>	5. <i>Retusa canaliculata</i>	5. <i>Ampelisca abdita</i>

STATIONS 8N, 13N CLUSTER

<u>STATION 8N</u>	<u>STATION 13N</u>
1. <i>Nephtys incisa</i>	1. <i>Streblospio benedicti</i>
2. <i>Streblospio benedicti</i>	2. <i>Oligochaeta</i>
3. <i>Oligochaeta</i>	3. <i>Tellina agilis</i>
4. <i>Mulinia lateralis</i>	4. <i>Nephtys incisa</i>
5. <i>Nereis succinea</i>	5. <i>Mulinia lateralis</i>

MORRIS COVE SHALLOW CLUSTER

<u>STATION A</u>	<u>STATION C</u>	<u>STATION G</u>
1. <i>Nereis succinea</i>	1. <i>Tellina agilis</i>	1. <i>Nereis succinea</i>
2. <i>Tellina agilis</i>	2. <i>Glycera americana</i>	2. <i>Glycera americana</i>
3. <i>Streblospio benedicti</i>	3. <i>Nereis succinea</i>	3. <i>Pagurus longicarpus</i>
4. <i>Glycera americana</i>	4. <i>Pagurus longicarpus</i>	4. <i>Tellina agilis</i>
5. <i>Pagurus longicarpus</i>	5. <i>Streblospio benedicti</i>	5. <i>Nassarius trivittatus</i>

occurrences in samples from this group were high compared to the total number of possible occurrences or the total number of samples). Because *Nereis* was ubiquitous, its fidelity for the group was found to be low (i.e., its constancy with the inner harbor cluster was not particularly higher than its constancy harborwide). *Nereis* was the subdominant at Station 5 where *Crangon* was dominant. However, *Crangon*, a motile epibenthic species, appears to have even lower fidelity than *Nereis*, occurring throughout the harbor in approximately the same frequency. *Streblospio benedicti* and *Capitella capitata*, two opportunistic polychaetes, also appear as subdominants in this grouping at two stations each. *Streblospio* occurs at high levels in one of the other groupings as well as this one, but *Capitella* exhibits high fidelity and appears as a dominant species in this grouping only. As might be expected, this cluster exhibits the best example of a stressed environment populated by several opportunistic species, primarily polychaetes.

A second cluster of three stations (A, C, G) also became apparent from the trellis diagram. These stations occupy a horseshoe-shape area around the northern and western periphery of Morris Cove. Although no sediment grain-size data were analyzed by either study, field sampling personnel have identified this area of Morris Cove as consisting of a coarse-grained usually muddy sand. This area is distinct from the very soft silt-clay sediments which are typical of the deeper central portions of Morris Cove. Station D, however, which is spatially contiguous to this cluster, and apparently consisting of a similar substratum, showed no particular affinity to this, or any other, cluster.

This second, well-defined cluster, occupying the shallower portions of Morris Cove is characterized by a somewhat more complex and diverse faunal assemblage (Table 6-9). *Nereis succinea* again occurs as the dominant species at two of the stations and as a subdominant at the third. Here, however, *Nereis* is accompanied by a number of codominants, some of which were not dominant in the inner harbor cluster. These include *Tellina agilis*, *Glycera americana*, *Streblospio benedicti* and *Pagurus longicarpus*. Of these, *Tellina* and *Pagurus* exhibit somewhat

greater fidelity as *Pagurus* occurs as a codominant only within this cluster, while *Tellina* reaches its greatest dominance here. *Streblospio* and *Glycera* are much more widespread in the harbor and appear as components of many communities.

The third and largest cluster, and the one which exhibits the highest affinities, occupies the central portion of Morris Cove. Included in this group are Stations B, E, F, I, H and 11N, which are in the shipping channel a short distance to the north of the Cove. This group of stations produced a very distinct cluster located in soft silt-clay substratum which may indicate an area of greater physical stability than the sediments characteristic of the (A, C, G) cluster.

The large group of stations in the central portion of Morris Cove exhibits the most distinct and consistent community in the harbor. The dominant species at each of the six component stations of this group is *Nephtys incisa*, a species which showed both constancy and fidelity for this cluster. The subdominant species at each of the six stations was one of three small bivalves, *Tellina agilis*, *Nucula proxima* or *Mulinia lateralis*. The ubiquitous pair of polychaete species (*Glycera* and *Streblospio*) was also present at nearly every station. Apparently, however, the deterministic faunal component of this community is the polychaete, *Nephtys*, accompanied by one of three bivalves.

One additional aspect of this *Nephtys* community that is somewhat unusual is the presence of the tubicolous amphipod, *Ampelisca* spp., at most of the stations. No amphipod species was present as a codominant in any of the other clusters. Since amphipods, particularly Ampeliscid amphipods, have become recognized as extremely pollution-sensitive, their presence in these Morris Cove samples indicates that this area is relatively unpolluted in relation to the rest of the harbor, particularly in regard to petroleum hydrocarbons.

An additional minor cluster of two spatially separated stations 8N and 13N, was also recognized. This small group is of limited

significance except that it is somewhat surprising that 13N did not group with either of the two Morris Cove clusters and that 8N, which is well up into the inner harbor, showed such strong affinity to a station from the control site. This particular station pair exhibited the strongest affinity observed in the program.

This fourth small cluster (Stations 8N and 13N) is of limited value in understanding the dynamics of the Harbor ecosystem and will only be treated briefly. These two stations appear to be composites of several components of the other three clusters. *Nephtys* and *Nereis* both appear as codominants. *Streblospio*, *Tellina* and *Mulinia* are also present. The controlling faunal component that appears to define this cluster, however, is the dominant position of *Streblospio* and Oligochaetes, which are generally not present with this frequency in other clusters. Were it not for the Oligochaete component, Station 8N would probably show stronger affinity for the large central Morris Cove group and 13N would cluster with the peripheral Morris Cove group.

The first and last of the groupings described above are faunistically sparse and difficult to relate to other estuaries. The two Morris Cove communities, however, bear resemblances to faunal assemblages that have been described from other areas. McGrath (1974) described a similar pattern of faunal distribution in Raritan Bay-Lower New York Harbor. The two communities in Raritan Bay, which is also a polluted estuary, were dominated by *Streblospio-Tellina* in coarser sediments as seen in New Haven Harbor and *Nephtys-Mulinia* in the muds.

Streblospio benedicti and *Tellina agilis* were described by McGrath et al. (1978) as two of the characterizing organisms of Clinton Harbor, a relatively unpolluted estuary a short distance to the north of New Haven. Other aspects of the benthic populations, including range of species richness, faunal density and diversity, as well as dominant species, were comparable between Clinton Harbor and Morris Cove stations in New Haven.

The community occupying the deeper portions of Morris Cove is similar to the *Nephtys incisa*-*Yoldia limatula* community of Long Island Sound described by Sanders (1956), and the *Nephtys*-*Nucula proxima* community of Buzzards Bay (Sanders, 1960). The primary difference between these communities and the assemblage at New Haven is that the latter has a lower species richness and faunal density than Long Island Sound or Buzzards Bay. The Morris Cove community also has a greater number of opportunistic species.

Reference to the literature and other areas in Long Island Sound indicates that the benthic fauna of New Haven Harbor is generally characteristic of a polluted estuary. Some faunal components of Morris Cove, however, correspond to those of less polluted areas, reflecting better water quality conditions in Morris Cove than in the inner harbor.

ANALYSIS OF IMPACTS

Power generating stations utilizing once-through cooling systems impact the marine benthic environment in a number of ways. The direct impact of the heated effluent may be sufficient to elevate temperatures in the receiving body of water to a point which is detrimental to the survival of some of the resident species. This type of impact may affect adults, juveniles, or larvae of benthic infauna. Further, heat may alter competitive advantages or behavior, indirectly producing mortality. Although the direct effects of heat on marine communities have received considerable attention from the public, they have been shown in many cases to be one of the least objectionable impacts of generating stations, and due to the buoyant nature of the discharge are not likely to impact benthic populations. There have been no measurable changes in bottom temperature at any benthic stations in New Haven Harbor. Further, as discussed in the physical-chemical section of this report (Section 3), there is no evidence to suggest that dissolved oxygen values in New Haven Harbor have decreased by any measurable amount due to the operation of New Haven Harbor Station.

Entrainment, the passage of the planktonic dispersal stages of many marine organisms through station cooling systems, often produces large mortalities (Enright, 1977). Nearly all of the dominant species in New Haven Harbor have planktonic larvae and are therefore potentially subjected to losses from this impact. In the absence of actual entrainment data, the effect of this impact must be inferred from recruitment patterns during appropriate seasons. Another type of impact, impingement, occurs when adults are trapped on the various screening systems at the station intake. While this type of impact may often be severe for finfish individuals, benthic infaunal invertebrate species are generally not subject to impingement losses.

Due to the low ratio of plant cooling water flow to the volume of water moved with each tide, the minimal harbor area experiencing heightened temperatures from the discharge plume, and the lack of direct plume contact with the benthic habitat, minimal impact of New Haven Harbor Station operations on the benthos was anticipated. Since there is minimal potential for plant impact on the subtidal benthos, particularly on any given spatially limited area, impact is not analyzed in great detail for individual stations. Instead, analysis consists of comparisons of diversity, species richness, general density and abundant species density between preoperational and operational periods at groups of stations within the harbor.

The addition of environmental stress to an already severely impacted ecosystem would be expected to result in the elimination of individuals and then species that are near their tolerance limits. This potential impact was evaluated by comparing the number of species collected in all samples taken prior to August 1975 with all samples collected after that date. The data were analyzed via a standard t-test with no correction for season as the species richness data show no obvious seasonality. No significant differences in mean number of species per station were found via this procedure ($t = -.0807$, $p > 0.9$). Because any potential impact of this nature would be most acute in the inner harbor these stations were tested separately and, again, no significant differences were found

between preoperational and postoperational species richness ($t = .4285$, $0.5 < p < 0.9$). Because late summer appears to be the period of greatest stress for populations in the harbor, the species richness data for August of 1974 were compared and paired by station, with similar data for 1975, 1976 and 1977. In all cases, results were not significant, indicating no decrease in summer species richness after operation of New Haven Harbor Station commenced.

Species Richness

The primary factor limiting the application of statistical analysis to the New Haven Harbor benthic data is the large degree of variability. The results of the three-way ANOVA to test the impact of year, season and station on species richness and faunal density indicate that all three factors and their interactions were significant ($p < .001$) for all parameters, with the exception of season vs. station. Numbers of taxa for each station-season combination were examined for significant differences between preoperational and postoperational data. For two of these comparisons (Station 8, spring; Station 13, summer) the results were significant, with greater numbers of taxa postoperationally at Station 8 and greater numbers of taxa preoperationally at Station 13. Because the transformation procedure was not successful in eliminating heteroscedasticity (unequal variance) for the faunal density data, and the overall results of the ANOVA indicate an apparently patternless variability, these contrasts were not analyzed for numbers of individuals. These results are indicative of a system with large and extremely variable changes in its faunal structure in both time and space. The only meaningful statistically significant relationship concerning species richness was that between the inner harbor and Morris Cove. The preoperational and postoperational species richness data were compared for inner harbor stations vs. Morris Cove stations and paired by sampling period. In both cases Morris Cove was found to contain significantly more species than the inner harbor (preoperational, $t = 4.5134$, $p < .001$; postoperational, $t = 5.628$, $p < .001$).

Species Density

Abundance data on the 14 characteristic species identified in Table 6-10 were evaluated for trends over the course of the study via Spearman's coefficient of rank correlation (Conover, 1971). The calculated correlation values and their significance levels are presented in Table 6-10. Of the 14 characteristic species, nine show a statistically significant tendency to increase in abundance over the course of the study.

Because 1977 was identified (see below) as a year of unusually high abundances, the data were re-ranked and Spearman's coefficient recalculated for the 12 collections from 1973 through 1976 only. Of the nine species showing significant increases in density over the entire study, six also showed significant increases from 1973 to 1976, indicating that the overall increase in faunal density during 1977 was not the only factor responsible for the trend toward greater densities among ubiquitous species.

Overall faunal density shows an increase from pre- to post-operational periods. This was examined for significance by seasonally paired t-tests conducted on the faunal density data for all possible combinations of years before and after plant operation. "Years" in this case refers to full years before or after operation and not calendar years. The resulting matrices of t values are shown in Table 6-11. Inspection of these results reveals that there has been no statistically significant change in faunal density at inner harbor stations over the course of the program, although the data do suggest a general increase in density. The only significant change in faunal density involves the Morris Cove data, where faunal densities were significantly higher in 1977 than in either 1974 or 1976. Densities were also greater than in 1975, although not significantly so. Increases in faunal density from preoperational to operational years at Morris Cove and inner harbor stations is not indicative of a positive Harbor Station impact on the benthic infaunal community. The general harborwide nature of the increase

TABLE 6-10. TRENDS IN MEAN DENSITY FOR 14 CHARACTERISTIC SPECIES EVALUATED VIA SPEARMAN'S RHO. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

SPECIES	INDICATED TREND	SIGNIFICANCE LEVEL	
		1974-1976	1974-1977
<i>Streblospio benedicti</i>	increase	p<.01	ns
<i>Nephtys incisa</i>	-	ns	ns
<i>Oligochaeta</i>	increase	p<.001	p<.05
<i>Glycera americana</i>	increase	p<.01	ns
<i>Nereis succinea</i>	-	ns	ns
<i>Polydora ligni</i>	increase	p<.01	p<.05
<i>Gemma gemma</i>	-	ns	ns
<i>Mulinia lateralis</i>	increase	p<.01	p<.05
<i>Tellina agilis</i>	increase	p<.01	ns
<i>Nassarius trivittatus</i>	increase	p<.01	p<.01
<i>Neomysis americana</i>	increase	p<.01	p<.05
<i>Crangon septemspinosa</i>	increase	p<.01	p<.01
<i>Nucula proxima</i>	-	ns	ns
<i>Pagurus longicarpus</i>	-	ns	ns

TABLE 6-11. RESULTS OF PAIRED T-TESTS FOR FAUNAL DENSITY CHANGES FOR ALL POSSIBLE PAIRS OF YEARS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

INNER HARBOR STATIONS

	1973 - 74	1974 - 75	1975 - 76
1974 - 75	.5687 (ns)	-	-
1975 - 76	.1220 (ns)	.4216 (ns)	-
1976 - 77	3.4741 (ns)	1.9705 (ns)	1.5259 (ns)

MORRIS COVE STATIONS

	1973 - 74	1974 - 75	1975 - 76
1974 - 75	.9062 (ns)	-	-
1975 - 76	.3676 (ns)		-
1976 - 77	5.376 (p<.05)	1.8210 (ns)	7.6475 (p<.05)

suggests either an improvement in water quality or, more likely, a random increase rather than a plant impact.

Diversity

Because the summer has been identified as the period of greatest stress for the benthic infauna in New Haven Harbor, power station effects on diversity should be most evident in the summer. To evaluate the possibility of reduced diversities in the inner harbor due to station operation, a series of paired t-tests was run on the Shannon-Weaver diversity values for the six stations closest to the discharge (4, 7, 8, 8N, 5, 9) and six control stations from Morris Cove. A matrix of comparisons for each location over all years was constructed (Table 6-12) from the results.

For all comparisons except one, there is no significant difference between the mean diversity at the selected stations for pre-operational vs. postoperational years. The single exception is for 1974 compared with 1976 at Morris Cove, where diversities were significantly greater in 1976 ($p < .05$). This isolated observation is of no general significance and the observed pattern of minimal changes in diversity supports the conclusion of no apparent impact on benthic macrofaunal diversity due to station operation.

SUMMARY

A composite list generated by the NAI (1973-1977) and R & M (1974-1978) benthic studies in New Haven Harbor consists of over 300 taxa. Species richness values did not have consistent seasonal patterns but were higher at Morris Cove than in the inner harbor. Faunal diversity in the inner harbor was typically low; values of 0.0 were common. Diversities were higher in Morris Cove than in the inner harbor. A slight trend of increasing diversity was observed over the course of the

TABLE 6-12. RESULTS OF PAIRED T-TESTS FOR DIVERSITY (H') CHANGES FOR ALL POSSIBLE PAIRS OF YEARS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

INNER HARBOR STATIONS

	1973 - 74	1974 - 75	1975 - 76
1974 - 75	1.1078 (ns)	-	-
1975 - 76	.6767 (ns)	.3827 (ns)	-
1976 - 77	.0124 (ns)	.5792 (ns)	.3953 (ns)

MORRIS COVE STATIONS

	1973 - 74	1974 - 75	1975 - 76
1974 - 75	.8806 (ns)	-	-
1975 - 76	3.0732 ($p < .05$)	.3854 (ns)	-
1976 - 77	2.4842 (ns)	1.5251 (ns)	1.1513 (ns)

study. Faunal density was extremely variable with an annual minimum in summer and a maximum in winter. The summer minimum or "August effect" in New Haven Harbor appears to have been associated with the combined stresses of low dissolved oxygen, organic rich silt-clay substrata, and an inner harbor location.

Analysis of species richness, faunal density and diversity for significant changes between preoperational and operational periods revealed no apparent impact of the New Haven Harbor Station on the benthic infaunal assemblages of New Haven Harbor.

LITERATURE CITED -- SUBTIDAL BENTHOS

- Conover, W. J. 1971. Practical nonparametric statistics. Wiley, New York. 462 pp.
- Dean, D. 1970. Water quality -- benthic invertebrate relationships in estuaries. Ira C. Darling Center for Research, Teaching and Service, Walpole, Maine. Mimeo report.
- _____. 1975. Raritan Bay macrobenthos survey, 1952-1960. NOAA/NMFS data Report 99. Seattle, Washington, 51 pp.
- Enright. 1977. Power Plants and Plankton. Marine Pollution Bulletin, 8(7):158-163.
- Fisher, J. B. and P. L. McCall. 1973. The effect of environmental perturbations on benthic communities: an experiment in benthic recolonization and succession in Long Island Sound. Unpublished report. Dept. Geology and Geophysics, Yale University. 33 pp.
- Jones, D. J. 1972. Changes in the ecological balance of invertebrate communities in kelp holdfast habitats of some polluted North Sea waters. Helgoländer wiss. Meeresunters. 23:248-260.
- _____. 1952. The bottom fauna and the food of flatfish off the Cumberland Coast. J. Anim. Ecol. 21:182-205.
- McCall, P. L. 1977. Community patterns and adaptive strategies of the infaunal benthos of Long Island Sound. J. Mar. Res. 35:221-266.
- McGrath, R. A. 1974. Benthic macrofaunal census of Raritan Bay -- preliminary results. Pap. No. 24. 3rd Symp. Hudson River Ecol. Mar 22-23, 1973. Bear Mt., New York, Hudson River Environ. Soc.
- _____ and A. D. Michael. 1978. Environmental assessment of the Clinton Harbor, Connecticut estuary. Report to Flaherty-Giavara Assoc., New Haven, Connecticut. 60 pp. & appendices.
- Normandeau Associates, Inc. 1973. New Haven Harbor Ecological Studies, New Haven, Connecticut. Annual Report 1971-1972 for The United Illuminating Company, New Haven, Connecticut. 208 pp.
- _____. 1974a. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1972-1973 for The United Illuminating Company, New Haven, Connecticut. 215 pp.
- _____. 1974b. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Interim Report May-December 1973 for The United Illuminating Company, New Haven, Connecticut. 199 pp.

- _____. 1975a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1974 for The United Illuminating Company, New Haven, Connecticut. 223 pp.
- _____. 1975b. Ecological studies conducted at selected sites in New Haven Harbor, Connecticut. 114 pp.
- _____. 1976. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1975 for The United Illuminating Company, New Haven, Connecticut. 312 pp.
- _____. 1977a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1976 for The United Illuminating Company, New Haven, Connecticut. 376 pp.
- _____. 1977b. Piscataqua River Ecological Studies 1976. Monitoring Study Report No. 7 for Public Service Company of New Hampshire.
- Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Am. Rev.*, 16, pp. 229-311.
- Pielou, E. C. 1966. The measurement of diversity in different types of biological collections. *Theoret. Biol.* 13:131-144.
- _____. 1975. Ecological diversity. Wiley, New York. 165 pp.
- Reish, D. J. 1961. A study of benthic fauna in a recently constructed boat harbor in southern California. *Ecology*. 42:84-91.
- _____, T.J. Kawling and A.J. Mearns. 1975. Marine and estuarine pollution. *J. Water Pollution Control Federation* 47(6):1617-1635.
- Rhoads, D. C. and A. D. Michael. 1975. Benthic monitoring study for The United Illuminating Company Coke Works Site Power Plant. Report I: Baseline data 1974. Unpublished report. 22 pages and appended data sheets.
- _____. 1976. Benthic monitoring study for The United Illuminating Company Coke Works Site Power Plant. Report II: Benthic monitoring during plant testing and early operation 1975. Unpublished report. 8 pages and appended data sheets.
- _____. 1977. Benthic monitoring study for The United Illuminating Company Coke Works Site Power Plant. Report III: Benthic monitoring during plant testing and early operation 1976. Unpublished report. 10 pages and appended data sheets.
- _____. 1978. Benthic monitoring study for The United Illuminating Company Coke Works Site Power Plant. Report IV: Benthic monitoring during plant testing and early operation 1978. Unpublished report. 11 pages and appended data sheets.

_____, McCall and Yingst. In Press. The ecology of sea-floor disturbances. Am. Scientist.

Sanders, H.L. 1956. Oceanography of Long Island Sound, 1952-1954. X. The biology of marine bottom communities. Bull. Bingham Oceanogr. Coll. 15:345-413.

_____. 1960. Benthic studies in Buzzards Bay. III. The structure of the soft-bottom community. Limnol. Oceanogr. 5:138-158.

Wass, M.L. 1967. Biological and physiological basis of indicator organisms and communities. IN: T.A. Olson and F.J. Burgess, Pollution and Marine Ecology, Interscience, New York. pp. 271-283.

Wigley, R.L. 1965. Density-dependent food relationships with reference to New England groundfish. ICNAF Spec. Publ. 6:583-589.

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

7.0 INTERTIDAL
by Stephen Dudley and Catherine D. Harvell

Normandeau Associates, Inc.
Bedford, N. H.

TABLE OF CONTENTS

	PAGE
INTRODUCTION.	7-1
METHODS	7-3
CHARACTERIZATION OF NEW HAVEN HARBOR INTERTIDAL FAUNA	7-4
Dominant Species.	7-10
COMPARISON OF NEW HAVEN HARBOR WITH OTHER LONG ISLAND SOUND SITES	7-20
ANALYSIS OF IMPACT.	7-21
SUMMARY	7-27
LITERATURE CITED.	7-28

LIST OF FIGURES

	PAGE
7-1. Intertidal areas sampled in New Haven Harbor from May 1971 through October 1977.	7-2
7-2. Population densities of dominant molluscs, <i>Mya arenaria</i> , <i>Gemma gemma</i> , <i>Ilyanassa obsoleta</i> and <i>Macoma balthica</i> by station at intertidal areas in New Haven Harbor 1971 through 1977	7-11
7-3. Population densities of dominant polychaete taxa, <i>Nereis succinea</i> , Spionidae, Capitellidae and <i>Nereis</i> spp., by station at intertidal areas in New Haven Harbor 1971 through 1977	7-18
7-4. Population densities of dominant arthropods, <i>Balanus improvisus</i> and <i>Limulus polyphemus</i> by station at intertidal areas in New Haven Harbor 1971 through 1977. . . .	7-19

LIST OF TABLES

7-1. OCCURRENCE OF INTERTIDAL INVERTEBRATES FROM MAY 1971 THROUGH OCTOBER 1977 AT ALL STATIONS IN NEW HAVEN HARBOR	7-5
7-2. DOMINANT TAXA COMMONLY COLLECTED AT NEW HAVEN HARBOR INTERTIDAL STATIONS FROM 1971 THROUGH 1977	7-8
7-3. TOTAL NUMBERS OF ORGANISMS ($\#/M^2$) COLLECTED AT INTERTIDAL STATION TRANSECTS FROM 1971 THROUGH 1977	7-8
7-4. NUMBERS OF TAXA COLLECTED AT INTERTIDAL STATION TRANSECTS FROM 1971 THROUGH 1977	7-9
7-5. MEAN LENGTHS (MM) OF <i>MYA ARENARIA</i> COLLECTED ON NEW HAVEN HARBOR INTERTIDAL TRANSECTS FROM MAY 1971 THROUGH MAY 1977	7-9
7-6. ABUNDANT TAXA COLLECTED ON EAST SHORE INTERTIDAL TRANSECTS DURING MAY AND OCTOBER FROM 1971-1977.	7-12
7-7. ABUNDANT TAXA COLLECTED ON SANDY POINT INTERTIDAL TRANSECTS IN MAY AND OCTOBER FROM 1971-1977.	7-13
7-8. ABUNDANT TAXA COLLECTED ON LONG WHARF INTERTIDAL TRANSECTS IN MAY AND OCTOBER FROM 1971-1977.	7-14
7-9. THE MOST ABUNDANT TAXA COLLECTED AT INTERTIDAL STATIONS DURING PREOPERATIONAL YEARS.	7-24
7-10. FAUNAL DOMINANCE BASED ON PERCENT OCCURRENCE IN ALL SAMPLE SETS FOR EACH INTERTIDAL STATION DURING PRE-OPERATIONAL AND OPERATIONAL SAMPLING PERIODS	7-25

7.0 INTERTIDAL

by Stephen Dudley and C. Drew Harvell

Normandeau Associates, Inc.
Bedford, N. H.

INTRODUCTION

The intertidal zone is the most physically variable habitat in an estuarine environment (Caspers, 1967). Floral and faunal ecology is regulated by a changing physical/chemical regime and biological processes such as predation and competition (Connell, 1961; Paine, 1966; Dayton, 1971). Organisms inhabiting the intertidal flats are an important component of the estuarine ecosystem since they act as a food source for shore-zone fishes, shorebirds and waterfowl.

New Haven Harbor is an urbanized estuary containing over 600 acres of intertidal habitat, consisting of soft-substrate flats with little algal growth. More than half of this area is located in the inner harbor (Figure 7-1). Industrial and municipal wastes added to the normally fluctuating physical/chemical regime produce a harsh environment for sessile marine taxa. New Haven Harbor intertidal taxa typify those characterized by Anger (1975) as organic pollution indicators. Organic waste enters New Haven Harbor from four sewage treatment plant (STP) outfalls (Figure 7-1) rendering the inner harbor area unsuitable for public recreational purposes according to state standards (Conn. State D.E.P., 1978).

The intertidal area is particularly sensitive to buoyant effluents that can impact the habitat through contact or deposition by tidal action. A small oil spill (not related to New Haven Harbor Station operation) occurred in New Haven Harbor during the study period (October 6, 1974), but, a special study did not detect any significant impact by the floating oil slick. Impingement of buoyant heated discharge water is a possible source of powerplant impact on the intertidal habitat; however, hydrographic data indicate that impingement of the thermal plume on any intertidal area is minimal in New Haven Harbor.

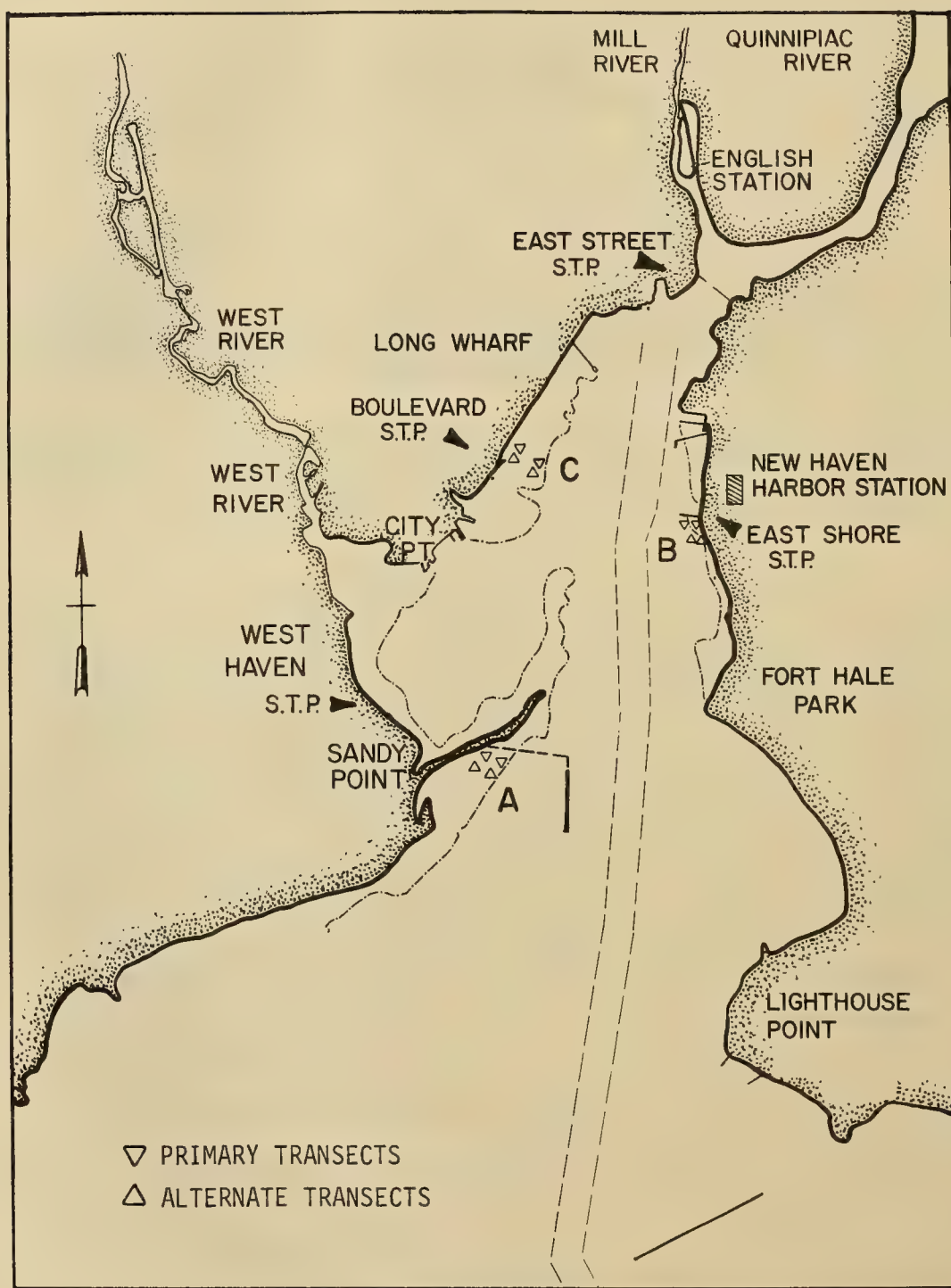


Figure 7-1. Intertidal areas sampled in New Haven Harbor from May 1971 through October 1977 on (A) Sandy Point, (B) East Shore and (C) Long Wharf transects. New Haven Harbor Ecological Studies Summary Report, 1979.

The purpose of this study was twofold: 1) to characterize the New Haven Harbor intertidal community with respect to temporal and spatial patterns of species distribution and abundance, and 2) to establish a data base of preoperational (1971-1975) and operational (1975-1977) data from which to analyze any potential impact from the station.

METHODS

Intertidal fauna were sampled at three stations in New Haven Harbor in May (spring) and October (fall) from 1971 through 1977 except October 1977 at Sandy Point (Figure 7-1). The intertidal area at Sandy Point station was not exposed at that time, apparently due to erosion and slumping associated with nearby dredging. Permanent transects were established in 1971 at the stations marked in Figure 7-1 as follows: (a) Sandy Point - transect extended north-south on the south side of Sandy Point about 150 meters west of the beginning of the breakwater. A parallel reserve transect was marked off 50 meters closer to the breakwater. Although not sampled, such reserve transects were established and maintained throughout the study in case some drastic change occurred in the primary sampling transect. (b) East Shore -- this station was closest to the Harbor Station discharge. It was sampled using a transect running east-west about 75 meters south of Harbor Station pier. A parallel reserve transect was marked off an added 50 meters to the south. (c) Long Wharf -- the transect northwest-southeast about 450 meters west of Long Wharf. The reserve transect was established 50 meters closer to Long Wharf. Sediments along the transects ranged from soft mud at the Long Wharf station, to firm, muddy sand at both Sandy Point and East Shore Stations.

Duplicate $1/16\text{m}^2$ samples were taken at low and mid-intertidal areas along each of three primary transects (four samples per transect). Sediments were removed to a depth of 25 cm and sieved through 2 mm mesh screens to separate macrofauna from sediments. Collected fauna were then preserved in buffered formalin and returned to the laboratory where the species were identified and counted.

Species were analyzed for abundance ($\#/m^2$) and frequency of occurrence (percent occurrence). High percent occurrence (number of sample periods a taxon was present divided by total number of sample periods) was used to identify species that were consistently present, including those that were low in abundance. Abundant taxa were those which characterized a station, based on their higher relative abundances in samples (Table 7-4). Overall dominance (common taxa) was determined by ranking all taxa collected both by frequency of occurrence in samples over seven years and by total abundance over the same period. Rank scores were assigned to taxa on both lists (i.e., the taxon ranked first was given a score of 1, second ranked 2, etc.). Scores for each taxon were added from both lists and the lowest 10 scoring taxa were designated as dominant (Table 7-1). Species richness (total number of taxa) was used as a measure of diversity for a given station or year.

Obvious constraints are imposed upon interpretation of results by the complexity of the intertidal environment as well as the temporally-limited (semi-annual) sampling regime. The abbreviated sampling regime was selected because of the minimal plant operational impact anticipated in the intertidal area; spring and fall sampling were most likely to reflect any changes in faunal overwintering success and recruitment. Knowledge of unrecorded interim events would have simplified interpretation of the data; nonetheless it is clear that any major changes in the community habitat would have been evident.

CHARACTERIZATION OF NEW HAVEN HARBOR INTERTIDAL FAUNA

During the seven-year period of biological monitoring along intertidal transects in New Haven Harbor, a total of 90 invertebrate taxa and 6914 individuals were collected (Table 7-1). Of the 90 taxa, 22 were represented by only one or two individuals, and 60 taxa were found in either one (35 taxa), two (18 taxa) or three (7 taxa) sample sets. Samples taken at a given station in a single month and tidal period were considered a sample set. *Mya arenaria*, *Nereis succinea*,

TABLE 7-1. OCCURRENCE OF INTERTIDAL INVERTEBRATES FROM MAY 1971 THROUGH OCTOBER 1977 AT ALL STATIONS IN NEW HAVEN HARBOR. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

[illegible]

Continued

P₁ = Present but not enumerated

Gemma gemma, *Ilyanassa obsoleta*, and *Macoma balthica* (Table 7-2) were consistently the most common taxa collected. Species richness and density showed seasonal fluctuations with fall maxima. Sandy Point station showed the greatest species richness and highest density of individuals of the three stations sampled (Tables 7-3, 7-4), while East Shore usually showed lowest numbers and lowest species richness.

Species density generally increased from spring to fall with low values again the following spring. Fall maxima were related to spring and summer recruitment which was often heavy for certain dominant taxa. Spring recruitment was usually not evident in May because the newly settled juveniles were too small for retention by the 2-mm mesh screen used for sieving. The low spring densities relative to those in the fall seen in many years are indicative of either predation or natural overwinter mortality. The most severe overwinter mortalities as evidenced by reduced spring density occurred at East Shore in 1971, 1972, 1973 and 1977. Winter mortality was pronounced in *Mya arenaria*, a dominant species for which size data are available (Table 7-5). *Mya* grow about 10 mm per year, on the average, for about seven years (more in the first year, less after 3 years) (Newcombe, 1935). *Mya* in New Haven Harbor seldom survive past the length of 25 mm, indicating mortality in either the first or second year. At East Shore absence of clams in 1972 and spring 1973 and smaller clams in spring 1974, suggests an inability to overwinter (Table 7-5). At Long Wharf, spring clams were consistently larger than fall clams, suggesting overwinter success and growth. High winter mortality occurring at East Shore was probably related to the station's exposure to winter north winds which pile ice on intertidal areas and increase wind and wave erosion. Both Sandy Point and Long Wharf are lee shores with respect to northwest winds and may not be as heavily impacted by winter weather.

Annual variability in density characterized the intertidal community over the seven-year study period. The overall variation was most pronounced at East Shore and Long Wharf (Table 7-3) due to large fluctuations in *Mya* density. The highest densities of *Mya* were observed

TABLE 7-2. DOMINANT TAXA COMMONLY COLLECTED AT NEW HAVEN HARBOR INTERTIDAL STATIONS FROM 1971 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

RANK ¹	TAXA
1	<i>Mya arenaria</i> (soft-shell clam)
2	<i>Nereis succinea</i> (sand worm)
3	<i>Nereis</i> spp. ² (sand worm)
4	<i>Gemma gemma</i> (gem shell)
5	<i>Ilyanassa obsoleta</i> (mud snail)
6	<i>Macoma balthica</i> (macoma clam)
7	<i>Balanus improvisus</i> (barnacle)
8	Spionidae (spionid worms)
9	<i>Limulus polyphemus</i> (horseshoe crab)
10	Capitellidae (capitellid worms)

¹ Based on frequency of presence in a sample and total abundance

² May be primarily juvenile *N. succinea*

TABLE 7-3. TOTAL NUMBERS OF ORGANISMS (#/M²) COLLECTED AT INTERTIDAL STATION TRANSECTS FROM 1971 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

YEAR	EAST SHORE		LONG WHARF		SANDY POINT	
	MAY	OCT	MAY	OCT	MAY	OCT
1971	16	112	0	300	404*	732
1972	4	396	692	860	564	1260
1973	24	2972	312	564	1934	672
1974	300**	604**	260	6564	132	2040
1975	232	400	676	1288	828	1296
1976	192**	52	296	84	1620	1576
1977	36	4344	64	2852	944	NS
$\bar{X}$ ALL YEARS	114	1268	328	1784	918	1262
$\bar{X}$ PRE- OPERATIONAL	115	1009	388	2072	772	1176
$\bar{X}$ OPERATIONAL	114	1598	180	1408	1282	1436

*Does not include *Balanus* which were observed but not enumerated in May 1971.

**High densities of *Limulus* eggs collected in samples

NS Transects not sampled

TABLE 7-4. NUMBERS OF TAXA COLLECTED AT INTERTIDAL STATION TRANSECTS FROM 1971 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

YEAR	EAST SHORE		LONG WHARF		SANDY POINT	
	MAY	OCT	MAY	OCT	MAY	OCT
1971	5	2	0	3	10	4
1972	1	5	4	10	6	4
1973	3	10	5	7	9	14
1974	5	11	7	14	11	12
1975	10	8	12	11	14	16
1976	7	3	8	5	12	19
1977	5	14	8	11	8	NS
$\bar{X}$ All Years	5	8	6	9	10	12
$\bar{X}$ Preoperational	5	7	6	8.5	10	10
$\bar{X}$ Operational	6	8	8	9	10	12

NS Transects not sampled - Station had been dredged away.

TABLE 7-5. MEAN LENGTHS (MM) OF *MYA ARENARIA* COLLECTED ON NEW HAVEN HARBOR INTERTIDAL TRANSECTS FROM MAY 1971 THROUGH MAY 1976*. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

YEAR	EAST SHORE		LONG WHARF		SANDY POINT	
	MAY	OCT	MAY	OCT	MAY	OCT
1971	17.0	7.6	-	11.6	30.0	13.5
1972	-	-	18.8	10.8	28.0	15.3
1973	-	14.5	23.0	10.0	-	9.4
1974	10.0	12.7	26.6	13.3	12.0	-
1975	26.8	21.0	15.6	14.3	14.0	17.0
1976	17.0	ND	24.2	ND	-	ND

* Subsequent size data not available
ND = No data

at East Shore in October 1973 and 1977 and at Long Wharf in October 1974 and 1977 (Figure 7-2).

Although variable, no trends were apparent in annual species richness values, except a slight increase from 1971 to 1977 (Table 7-4). A seasonal trend was fairly consistent: generally, richness was greater in fall than spring, related to spring/summer recruitment and winter "die off". The greatest number of species occurred at Sandy Point, possibly related to its protected nature as discussed above, and its proximity to cleaner, outer harbor waters. Lowest species richness occurred at East Shore for most years and overall.

Ten taxa were selected as overall dominants whose distribution at particular stations was fairly consistent (Table 7-1). At East Shore, fauna were sparse in May, except for moderate numbers of annelids and molluscs. In October, *Mya arenaria*, *Balanus improvisus* and *Nereis succinea* were abundant for four out of seven years, and *Limulus polyphemus* for three (Table 7-6). At Sandy Point, *Ilyanassa obsoleta* was abundant in spring/fall for most years and *Gemma gemma* for the first three years and spring 1974 (Table 7-7). At Long Wharf *Mya* was the main dominant, with *Nereis* occurring in lesser numbers for most years (Table 7-8). Of the dominant species, four appeared in all sample periods: *Nereis succinea*, *Mya arenaria*, *Ilyanassa obsoleta*, and *Gemma gemma*.

Dominant Species

Population densities of dominant species in New Haven Harbor, as indicated by the sampling program, are presented by station and month in Tables 7-6 through 8. Most species showed trends in spatial and temporal distribution. The eight highest ranked species (Table 7-2) are discussed in some detail below.

The soft-shell clam (*Mya arenaria*) was the most numerous bivalve sampled in the New Haven Harbor intertidal community (Figure 7-2).

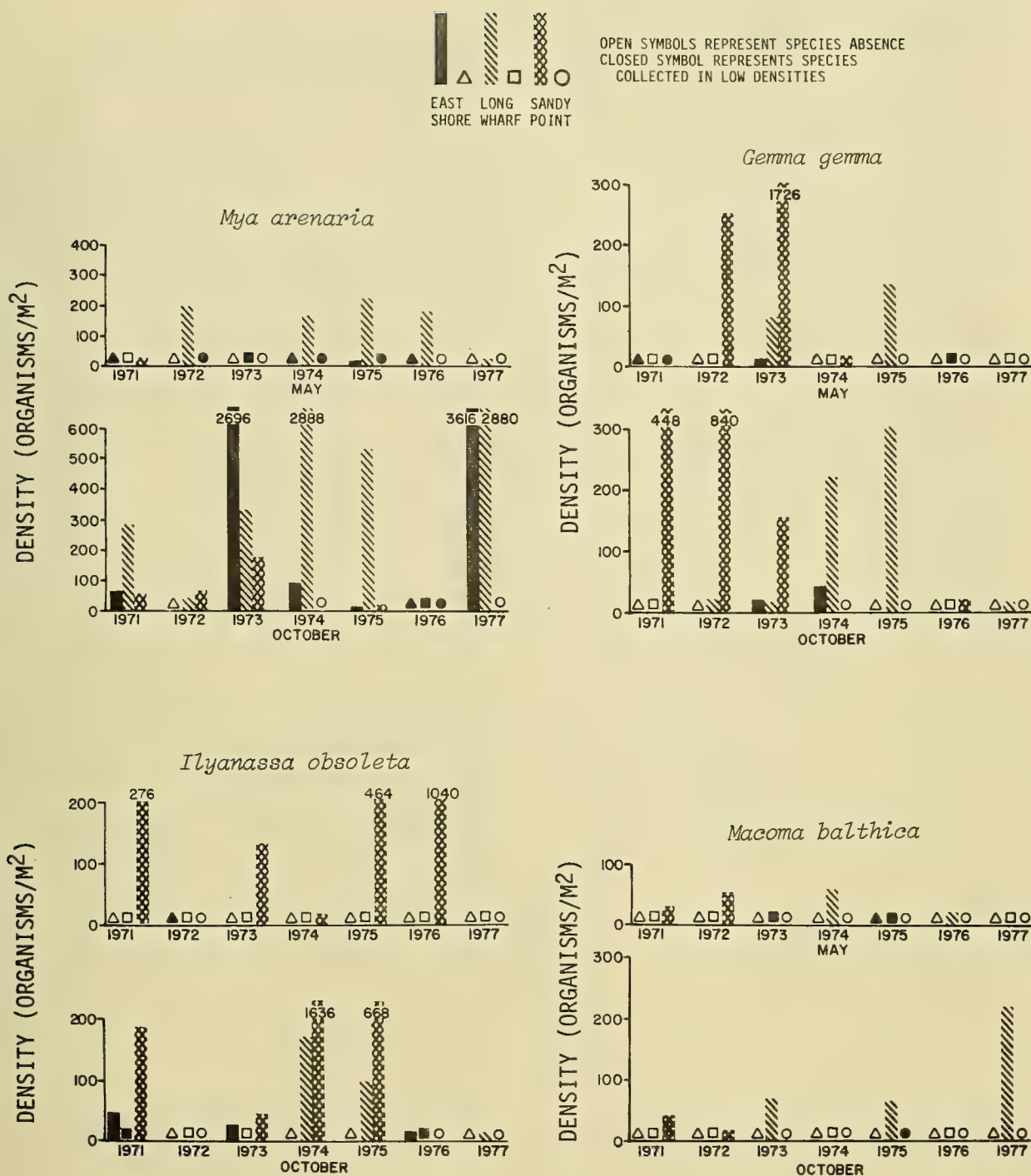


Figure 7-2. Population densities of dominant molluscs, *Mya arenaria*, *Gemma gemma*, *Ilyanassa obsoleta* and *Macoma balthica* by station at Intertidal Areas in New Haven Harbor 1971 through 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 7-6. ABUNDANT TAXA COLLECTED ON EAST SHORE INTERTIDAL TRANSECTS DURING MAY AND OCTOBER FROM 1971-1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

MAY			OCTOBER	
YEAR	TAXA	#/m ²	TAXA	#/m ²
1971	(few taxa collected)		<i>Mya arenaria</i> <i>Ilyanassa obsoleta</i>	64 48
1972	(few taxa collected)		<i>Balanus improvisus</i> <i>Nereis</i> spp. Orbinidae	196 100 64
1973	<i>Gemma gemma</i> (few taxa collected)	12	<i>Mya arenaria</i> <i>Nereis succinea</i> <i>Balanus improvisus</i> Spionidae	2696 100 48 32
1974	<i>Littorina obtusata</i> Capitellidae <i>Mytilus edulis</i> (<i>Limulus</i> eggs 9468)	128 92 72	<i>Limulus polyphemus</i> <i>Balanus improvisus</i> <i>Mya arenaria</i> <i>Gemma gemma</i> <i>Nereis virens</i> (<i>Limulus</i> eggs 3184)	276 112 92 40 36
1975	Oligochaetes Capitellidae <i>Scolecopides viridis</i> <i>Mya arenaria</i>	112 60 16 16	<i>Limulus polyphemus</i> <i>Scoloplos fragilis</i> <i>Nereis succinea</i>	172 140 28
1976	<i>Scoloplous</i> sp. Spionidae (<i>Limulus</i> eggs 820)	132 28	<i>Spio filicornis</i> <i>Ilyanassa obsoleta</i>	28 16
1977	Oligochaetes	16	<i>Mya arenaria</i> <i>Limulus polyphemus</i> <i>Nereis succinea</i> <i>Balanus improvisus</i> <i>Scoloplos</i> sp.	3616 292 180 76 72

TABLE 7-7. ABUNDANT TAXA COLLECTED ON SANDY POINT INTERTIDAL TRANSECTS IN MAY AND OCTOBER FROM 1971-1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

MAY			OCTOBER	
YEAR	TAXA	#/m ²	TAXA	#/m ²
1971	<i>Ilyanassa obsoleta</i>	276	<i>Gemma gemma</i>	448
	<i>Macoma balthica</i>	32	<i>Ilyanassa obsoleta</i>	188
	<i>Modiolus modiolus</i>	28	<i>Mya arenaria</i>	56
	<i>Mya arenaria</i>	24	<i>Macoma balthica</i>	40
	<i>Nereis succinea</i>	24		
1972	<i>Gemma gemma</i>	252	<i>Gemma gemma</i>	840
	<i>Nereis succinea</i>	136	<i>Nereis</i> spp.	172
	<i>Nereis</i> spp.	108	<i>Nereis succinea</i>	80
	<i>Macoma balthica</i>	52	<i>Mya arenaria</i>	64
			<i>Nassarius trivittatus</i>	56
1973	<i>Gemma gemma</i>	1726	<i>Mya arenaria</i>	180
	<i>Ilyanassa obsoleta</i>	132	<i>Gemma gemma</i>	152
	<i>Nereis</i> spp.	33	<i>Balanus improvisus</i>	108
			<i>Polydora</i> sp.	72
			<i>Ilyanassa obsoleta</i>	44
1974	<i>Gemma gemma</i>	20	<i>Ilyanassa obsoleta</i>	1636
	<i>Ilyanassa obsoleta</i>	16	Cirratulidae	224
	Spionidae	16	<i>Balanus improvisus</i>	76
			Spionidae	20
1975	<i>Ilyanassa obsoleta</i>	464	<i>Ilyanassa obsoleta</i>	668
	Cirratulidae	240	Cirratulidae	524
	Spionidae	32		
1976	<i>Ilyanassa obsoleta</i>	1040	<i>Spio filicornis</i>	1156
	<i>Scolecopides viridis</i>	412	<i>Pectinaria gouldii</i>	136
	Spionidae	52	Oligochaetes	68
	Cirratulidae	52	<i>Balanus improvisus</i>	32
			<i>Nereis succinea</i>	28
1977	<i>Scoloplos robustus</i>	420	No samples taken	
	<i>Spio filicornis</i>	380		
	<i>Balanus improvisus</i>	48		
	<i>Protodrilus</i> sp.	40		

TABLE 7-8. ABUNDANT TAXA COLLECTED ON LONG WHARF INTERTIDAL TRANSECTS IN MAY AND OCTOBER FROM 1971-1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

MAY			OCTOBER	
YEAR	TAXA	#/m ²	TAXA	#/m ²
1971	No fauna collected		<i>Mya arenaria</i>	284
1972	<i>Nereis</i> spp.	264	<i>Nereis</i> spp.	616
	<i>Nereis succinea</i>	220	<i>Nereis succinea</i>	120
	<i>Mya arenaria</i>	196	<i>Mya arenaria</i>	48
			<i>Gemma gemma</i>	24
			<i>Mitrella lunata</i>	24
1973	<i>Nereis succinea</i>	156	<i>Mya arenaria</i>	336
	<i>Gemma gemma</i>	80	<i>Macoma balthica</i>	72
	<i>Nereis</i> spp.	68	<i>Nereis succinea</i>	64
			Nereidae	56
			<i>Gemma gemma</i>	20
1974	<i>Mya arenaria</i>	160	<i>Mya arenaria</i>	4888
	<i>Macoma balthica</i>	64	<i>Polydora</i> sp.	960
	Nereidae	16	<i>Gemma gemma</i>	224
			<i>Ilyanassa obsoleta</i>	172
			<i>Nereis succinea</i>	96
1975	<i>Mya arenaria</i>	220	<i>Mya arenaria</i>	536
	<i>Gemma gemma</i>	136	<i>Gemma gemma</i>	304
	Capitellidae	96	<i>Ilyanassa obsoleta</i>	100
	<i>Nereis succinea</i>	92	Nereidae	92
	Neridae	84	<i>Nereis succinea</i>	72
1976	<i>Mya arenaria</i>	180	<i>Balanus improvisus</i>	60
	<i>Nereis succinea</i>	56	(few taxa collected)	
	<i>Macoma balthica</i>	24		
1977	<i>Mya arenaria</i>	20	<i>Mya arenaria</i>	2380
	(few taxa collected)		<i>Macoma balthica</i>	220
			<i>Nereis succinea</i>	100
			<i>Mulinia lateralis</i>	40
			<i>Gemma gemma</i>	20

Annual variability of *Mya* was pronounced at the East Shore transect. It showed highest numbers at Long Wharf and East Shore after 1973, reaching over 2000/m² for three years in October samplings. The high October abundances relative to spring, indicate a heavy spring/summer settlement and overwinter mortality. This coincides with *Mya* spawning in southern New England from May through November (Ropes and Stickney, 1965). After a planktonic life of about three weeks the larvae settle on a wide range of sediment types and establish themselves as sessile filter feeders where they are preyed upon by birds, bottom fish, *Limulus*, larger polychaetes, and crabs (TRIGOM, 1973). Individuals normally establish burrows at about 25 cm and subsequently spawn (Dowe and Wallace, 1957). Size data, as discussed above, indicate that *Mya* did not establish mature populations on the New Haven Harbor transects studied (Table 7-5). *Mya* populations apparently recruit from some other area in New Haven Harbor or Long Island Sound.

The gem clam (*Gemma gemma*) was the second most numerous bivalve in New Haven Harbor intertidal samples. It was most abundant at Sandy Point where it occurred from 1971 through 1973 (Figure 7-2). In 1974 and 1975 *Gemma* was numerous only at Long Wharf. In 1976 and 1977 it was found in low numbers at all stations. *Gemma* does not have a planktonic larval phase since the young are released from a brood as juveniles and settle in the immediate area inhabited by the adults (Sellmer, 1967). Because of this reproduction mode, dense, highly-localized colonies of *Gemma* tend to form. Brood release occurs about mid-summer and juveniles may grow to 2 mm by late fall (TRIGOM, 1973). If initial brood releases occur in mid-summer in New Haven, individual *Gemma* are probably too small in October to be retained on the 2 mm sieves used in this study. The populations of *Gemma* are probably subject to the same predatory pressures as described for *Mya*.

The macoma clam (*Macoma balthica*) was abundant at Sandy Point in 1971 and 1972 and at Long Wharf from 1973 to 1977 (Figure 7-2). *Macoma* spawns in late spring after which its planktonic larvae live in the water column about a month before settlement. Adults have been reported to live up to 25 years, feeding on detritus and other sediment

surface food sources (TRIGOM, 1973). Its predators are similar to those described for *Mya* and *Gemma*.

These three dominant bivalves were found in greatest numbers and with the highest frequency of occurrence at Long Wharf Station. Bivalves were numerous at Sandy Point Station from 1971 through 1973 but subsequently declined.

The only dominant gastropod, the mud snail (*Ilyanassa obsoleta*), was almost exclusively found at Sandy Point. Its presence was highly variable over time (Figure 7-2). In two years, 1972 and 1977, they were scarce or absent. By contrast, they were especially numerous from 1974 through 1976. Sediment changes that enhanced the substrate for occupation by *Ilyanassa* and discouraged the settlement of bivalves may have occurred at that station in 1972-1974. According to Jenner (1957), however, variable distributions are common. Reproduction of this deposit feeder (Scheltema, 1964) occurs in the summer when females deposit encapsulated eggs on a hard substrate where the embryos develop until hatching -- usually (depending on temperature) within a month. Released larvae have a planktonic stage and eventually settle and metamorphose (Scheltema, 1967). It is probable that the proximity of a rock jetty to the transect and the substrate it offers for egg capsule deposition is a factor influencing the occurrence of this gastropod on the Sandy Point transect.

The sandworm, (*Nereis succinea*), the most-common large polychaete in New Haven Harbor, is also considered to be the most ubiquitous polychaete in Long Island Sound intertidal areas (Sibley and Sibley, 1969). *Nereis* was common in most years at all stations, especially in October. May population abundances at East Shore were low in all years, and at Sandy Point and Long Wharf relatively high abundances during the period 1971-1973 decreased from 1974 through 1977 (Figure 7-3). *Nereis succinea* breeds in the water column by swarming in the evenings during summer months. Its larvae are planktonic and mature to deposit-feeding adults. Wass (1967) included *Nereis succinea* as one of a number of

pollution tolerant polychaetes. It was also one of two taxa which survived a summer exposed directly to a power-plant thermal effluent in York River, Virginia (Wariner and Brehmer, 1965), and was one of the few species collected in the discharge canal of LILCO's Northport Power Plant (Hechtel, 1970).

In addition to *N. succinea*, Capitellid worms (predominantly *Capitella capitata*) and Spionid worms (primarily *Polydora* sp.) were the other polychaetes which were abundant in New Haven Harbor. Cunningham (1972) reported *Capitella capitata* as the only capitellid he collected at Long Wharf; he also reported both *Polydora* sp. and *Streblospio benedicti* to be numerous spionids at his stations on the Long Wharf flat, especially in summer months. These taxa may have been more numerous but because of their size were not retained on the 2-mm mesh sieve used in the UI program. Cunningham used 0.25 and 0.5-mm mesh sieves. Capitellidae were absent at all New Haven stations during some sampling periods (Figure 7-3). When they were present, they were most numerous in May. Spionidae also exhibited highly variable distributions and densities (Figure 7-3). They were abundant only in October 1974 and 1975 at Long Wharf. Capitellids and Spionids have been rare at New Haven stations since May 1976. Both taxa are deposit feeders with planktonic larval stages. Wass (1967) and Daro and Polk (1973) both include *Capitella capitata* and *Polydora* sp. as pollution tolerant species.

Barnacles (*Balanus improvisus*) were the only abundant crustaceans collected. Because they settle on hard substrates, their population fluctuations were not accurately reflected in this sampling program; rather, *Balanus* abundances reflected chance collections of rocks with the infaunal samples. However, over time its relative distribution at the stations can be monitored. Naupliar, and cirripede larvae were numerous in summer plankton samples (Section 4.0) and barnacles were commonly found on any exposed shell, wood, or rock located within a sample area. *Balanus improvisus* was commonly collected at all stations in October but did not seem to overwinter well (Figure 7-4).

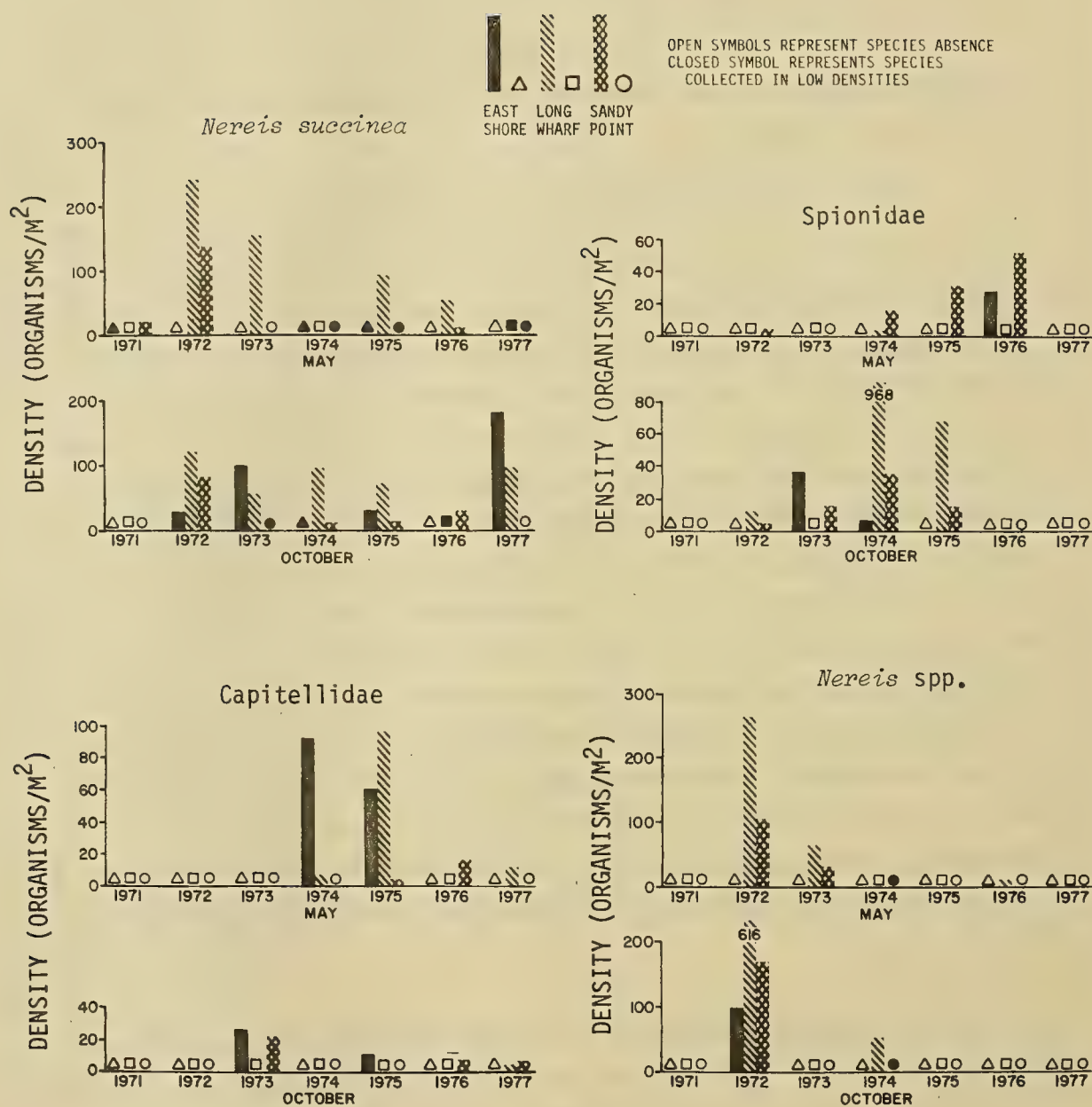


Figure 7-3. Population densities of dominant polychaete taxa, *Nereis succinea*, Spionidae, Capitellidae and *Nereis* spp., by station at Intertidal Areas in New Haven Harbor 1971 through 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

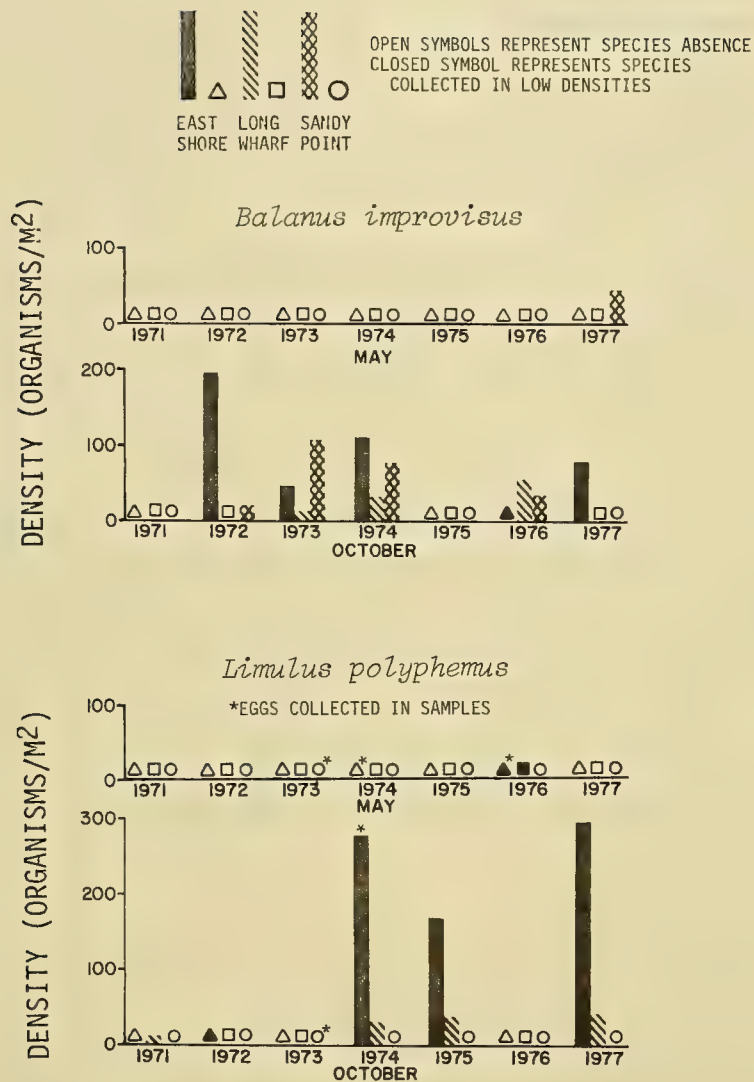


Figure 7-4. Population densities of dominant arthropods, *Balanus improvisus* and *Limulus polyphemus* by station at intertidal areas in New Haven Harbor, 1971 through 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

The horseshoe crab (*Limulus polyphemus*), was abundant during October samplings at East Shore station (Figure 7-4) in three of seven years studied. Reproduction has been reported to occur in May in this area (TRIGOM, 1973). Female crabs deposit their eggs in intertidal sediments where they are fertilized by the males. *Limulus* has no planktonic stage; eggs develop and hatch as juveniles. Both eggs and juveniles were commonly collected at East Shore. Juveniles and adults prey upon invertebrates such as bivalves and polychaetes in the shallow sediments (Shuster, 1950).

In summary, the fauna at intertidal stations studied in New Haven Harbor had lower species richness and greater variability within the harbor (i.e., Long Wharf and East Shore Stations) than in the outer harbor (i.e., Sandy Point). The taxa that characterized this habitat are ubiquitous in Long Island Sound and also tend to be those found in polluted environments elsewhere on the east coast. Many of these taxa, except for *Limulus polyphemus*, *Ilyanassa obsoleta*, and polychaetes, are sessile infaunal organisms that settle predominantly in summer. Overwinter survival was higher at Sandy Point than at inner harbor stations, as discussed. Variability from year to year in population densities was highly erratic, but this is normal for prolific taxa with pelagic larvae even in unaltered environments (NAI, 1977a, 1977b).

COMPARISON OF NEW HAVEN HARBOR WITH OTHER LONG ISLAND SOUND SITES

Dominant intertidal faunal components in New Haven Harbor were similar to those described independently in the same (Cunningham, 1972) and in other nearby urbanized estuaries. Cunningham examined the Long Wharf intertidal areas from 1971 to 1974 and described a faunal community similar to that described by NAI. Using smaller mesh sizes for sieves, he collected greater numbers of spionids, oligochaetes, and polychaetes (*Eteone heteropoda*) than were collected by our sampling techniques. Our study indicated greater *Mya* density than Cunningham estimated. These differing results for *Mya* indicate high spatial

heterogeneity in the fauna of the expansive Long Wharf intertidal flat. At Norwalk, Connecticut, *Gemma gemma*, *Ilyanassa obsoleta*, *Mya arenaria*, and *Scoloplos acutus* were most numerous (NAI, 1974). At Stamford Harbor the most numerous fauna were *Mya arenaria*, *Ilyanassa obsoleta*, *Nereis succinea*, and Spionidae (NAI, 1974). A Bridgeport Harbor study (NAI, 1973) indicated that *Nereis arenaceodonta*, *Scolecopelides viridis*, and *Spio setosa* were the most ubiquitous of the polychaetes, that the wide-ranging molluscs were *Ilyanassa obsoleta*, *Mya arenaria* and *Gemma gemma*, and that *Limulus polyphemus* was the most prevalent arthropod.

Other community parameters, such as seasonal species richness and abundance were variable between New Haven Harbor and other areas. In the current New Haven study, species richness and abundances were generally greatest in the October sample period, due to spring and summer recruitment. Cunningham's data also indicated high summer abundances in 1972 and 1973. At Stamford (NAI, 1974) sampling in July and October showed that samples taken in August 1971 and January, February, March and May of 1972 at low and mid-intertidal stations in Bridgeport yielded maximum summer species richness, but abundances were greatest in the winter, due to high year-round populations of polychaetes and bivalves (NAI, 1973).

ANALYSIS OF IMPACT

The purpose of the seven-year monitoring program was to detect any direct or indirect impacts of the United Illuminating Company generating station on the fauna of New Haven Harbor. The condenser-cooling system of New Haven Harbor Station is a potential source of impact on the intertidal fauna of the harbor. In general, the use of estuarine and oceanic water in power station cooling systems has resulted in high rates of invertebrate and fish larval mortalities for those entrained (Enright, 1977). However, Enright (1977) suggested that, due to high natural excesses of larvae produced, larval mortality from entrainment may not significantly influence adult settling populations.

The New Haven Harbor Station condenser-cooling water system takes in ambient temperature water and discharges effluent at 15°F above ambient (NAI, 1976b). Maximum plume temperature is reduced to 4°F above ambient at the surface in the immediate area of discharge (Section 3.0). No intertidal areas are directly impinged by the thermal effluent, according to isotherms plotted from infrared overflight data and temperature and dye studies (Section 3.0). It is possible that the East Shore transect could be minimally impinged under special wind and tide conditions, as it falls within the area of hydrographic Stations 8 and 9 which could be affected by a 0.9 to 1.8°F (0.5 to 1.0°C) increase (Section 3.0). However, planktonic larvae that are vital to maintenance and repopulation of intertidal areas might be moved some distance by the plume momentum or they might be stressed by contact with the plume, in either case altering settlement. Furthermore, the entrainment of eggs or pelagic larvae of intertidal community members could result in mortality or sublethal effects.

Indirect effects which thermal effluents may have on intertidal populations are numerous. Due to effluent discharge currents, changes may occur in circulation which promote erosion or increased sedimentation of an intertidal area. Food sources may be depleted if plankton abundance, a primary component in the diet of intertidal filter feeders, is reduced by entrainment; conversely, food could become more available as detritus due to entrainment mortality. Changes in predatory pressure may result from shifts in distribution and behavior of predators due to increased local temperatures. In New Haven Harbor, which already receives a variety of industrial and municipal wastes, heated effluents might encourage synergistic effects and therefore increase the toxicity of pollutants (Naylor, 1965). Preoperational dissolved oxygen concentrations in the harbor have been documented to be extremely low in the summer. This is unrelated to station operation and probably represents natural summer conditions of low dissolved oxygen solubility (Section 3.0). Thus numerous mechanisms exist which could affect the intertidal faunal composition of New Haven Harbor. These effects, whether positive or negative, could be manifested in sudden

changes in faunal composition and densities or they might occur slowly, detectable only by long-term monitoring. Either type of change would be masked by natural variability in the community and biological cycles affecting populations.

The intertidal fauna data collected at the three stations in New Haven Harbor were examined for evidence of thermal impact resulting from operation of the New Haven Harbor Station. A qualitative comparison of mean numbers of taxa (Table 7-3) indicates that species richness did not change substantially after operation began. A similar comparison of total numbers of organisms (Table 7-3) indicates that mean densities found at East Shore and Sandy Point during operational years were either similar or had increased over preoperational years. At Long Wharf, reduction in numbers is attributable to large natural variations in *Mya* densities.

Analysis of changes by sampling period showed considerable variability. Of particular interest were declines in faunal distribution and densities detected by October 1976 samples at the inner harbor stations, Long Wharf and East Shore. A similar depression was noted in the subtidal benthic populations of the inner harbor in an August 1976 sampling by Rhoads and Michael (1977). They believed that low levels of dissolved oxygen were responsible for observed die-offs. Low dissolved oxygen concentrations may also have caused the 1976 intertidal mortality. Because dissolved oxygen levels are not close to saturation values during the summer, plant operations do not further reduce concentrations (Section 3.0). October reductions in species richness and organism density were not observed in 1977, indicating that the die-off observed in 1976 was not a persistent summer phenomenon in New Haven Harbor.

Occurrences of dominant species over time are summarized in Tables 7-2 to 7-4 and by comparison of preoperational and operational periods in Tables 7-9 and 7-10. The results show that dominant fauna collected in preoperational samples were generally found at similar or

TABLE 7-9. THE MOST ABUNDANT TAXA COLLECTED AT INTERTIDAL STATIONS DURING OPERATIONAL YEARS (1971 THROUGH MAY 1975) AND DURING YEARS (OCTOBER 1975 THROUGH 1977). NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

		<u>EAST SHORE</u>	
PREOPERATIONAL	#/m ²	OPERATIONAL	#/m ²
<i>Mya arenaria</i>	319 *	<i>Mya arenaria</i>	728
<i>Balanus improvisus</i>	40	<i>Limulus polyphemus</i>	94
<i>Limulus polyphemus</i>	32	<i>Nereis succinea</i>	42
Capitellidae	20	<i>Scoloplos</i> sp.	41
<i>Nereis succinea</i>	20	<i>Balanus improvisus</i>	16
<i>Nereis</i> spp.	11		

		<u>LONG WHARF</u>	
PREOPERATIONAL	#/m ²	OPERATIONAL	#/m ²
<i>Mya arenaria</i>	682	<i>Mya arenaria</i>	624
<i>Nereis</i> spp.	128	<i>Gemma gemma</i>	66
<i>Polydora</i> sp.	107	<i>Macoma balthica</i>	62
<i>Nereis succinea</i>	83	<i>Nereis succinea</i>	49
<i>Gemma gemma</i>	54	<i>Ilyanassa obsoleta</i>	24
<i>Ilyanassa obsoleta</i>	20		
<i>Macoma balthica</i>	16		

		<u>SANDY POINT</u>	
PREOPERATIONAL	#/m ²	OPERATIONAL	#/m ²
<i>Gemma gemma</i>	382	<i>Ilyanassa obsoleta</i>	427
<i>Ilyanassa obsoleta</i>	306	<i>Spio filicornis</i>	384
Cirratulidae	52	Cirratulidae	144
<i>Mya arenaria</i>	38	<i>Scoloplos robustus</i> **	105
<i>Nereis</i> spp.	37	<i>Scolecopides viridis</i> **	103
<i>Nereis succinea</i>	29	<i>Pectinaria gouldii</i>	34
<i>Balanus improvisus</i>	23	<i>Balanus improvisus</i>	20
<i>Macoma balthica</i>	16	Spionidae	17
Spionidae	10	<i>Nereis succinea</i>	15

* Represents the mean of all observed densities converted to #/m².

** All individuals were collected in one sampling period.

TABLE 7-10. FAUNAL DOMINANCE BASED ON PERCENT OCCURRENCE IN ALL SAMPLE SETS FOR EACH INTERTIDAL STATION DURING PREOPERATIONAL AND OPERATIONAL SAMPLING PERIODS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

PREOPERATIONAL ¹	EAST SHORE %	OPERATIONAL ²	%
<i>Nereis succinea</i>	78	<i>Mya arenaria</i>	80
<i>Mya arenaria</i>	67	<i>Limulus polyphemus</i>	60
<i>Gemma gemma</i>	44	<i>Balanus improvisus</i>	40
<i>Ilyanassa obsoleta</i>	33	<i>Nereis succinea</i>	40
<i>Balanus improvisus</i>	33	<i>Oligochaetes</i>	40
<i>Capitallidae</i>	33		
PREOPERATIONAL	LONG WHARF %	OPERATIONAL	%
<i>Ilyanassa obsoleta</i>	78	<i>Nereis succinea</i>	100
<i>Gemma gemma</i>	78	<i>Mya arenaria</i>	100
<i>Mya arenaria</i>	78	<i>Ilyanassa obsoleta</i>	60
<i>Nereis</i> spp.	78	<i>Gemma gemma</i>	60
<i>Nereis succinea</i>	78	<i>Macoma balthica</i>	60
<i>Spionidae</i>	56	<i>Limulus polyphemus</i>	60
<i>Macoma balthica</i>	44		
<i>Glycera</i> spp.	44		
PREOPERATIONAL	SANDY POINT %	OPERATIONAL	%
<i>Mya arenaria</i>	89	<i>Nereis succinea</i>	80
<i>Nereis</i> spp.	78	<i>Tellina agilis</i>	60
<i>Nereis succinea</i>	67	<i>Mya arenaria</i>	40
<i>Gemma gemma</i>	56	<i>Ilyanassa obsoleta</i>	40
<i>Macoma balthica</i>	44	<i>Capitella capitata</i>	40
<i>Eteone</i> spp.	44		

¹Preoperational period 1971-1975 (27 sample sets - 9 samplings at each transect)

²Operational period 1975-1977 (15 sample sets - 5 samplings at each transect)

increased densities during plant operation. The Sandy Point station, closest to the outer harbor, was the most variable between preoperational and operational periods. *Gemma gemma* was numerous in preoperational years at Sandy Point but from mid-1975 onward was not commonly found. Also there were three polychaetes, *Spio filicornis*, *Scolecoplepides viridis*, and *Scoloplos robustus* which were not abundant in preoperational years but were collected in abundance during at least one sample period after operation began. Preoperational and operational frequency of occurrence by station is shown in Table 7-10. Most dominant species had similar values during preoperational and operational periods. Major changes at East Shore were drops in *Nereis succinia* and *Gemma gemma* frequency; *N. succinea* remained high at other stations. The decrease of *Nereis* is probably attributable to its high spatial heterogeneity compounded by the small number of sample sets from which values were calculated. In the preoperational period, *Gemma gemma* was present in abundances of less than $40/\text{m}^2$ at East Shore when present. Its ranking as a dominant is due to high preoperational numbers at Sandy Point. The operational period decrease at Sandy Point may indicate a harbor-wide decrease in *Gemma* populations which would not be likely to be related to station operation.

Gemma gemma was the only dominant species that showed a population change coincident with plant operation. *Gemma* populations declined at Sandy Point in May 1975 and at Long Wharf in October 1975, just prior to and after commencement of operations. Other bivalves, *Mya arenaria* and *Macoma balthica*, were scarce in October 1976 and May 1977 as discussed above, but by October 1977 densities had increased to previous levels. *Gemma*, which does not have a pelagic larval stage, must rely on successful local populations to reestablish itself. It may also have been a victim of a summer die-off.

None of the fluctuations in distribution and abundance in New Haven Harbor were suggestive of operational impact of New Haven Harbor Station on the intertidal fauna. The dominant taxa collected in the New Haven Harbor intertidal zone are characteristic of opportunistic species

as defined by Grassle and Grassle (1974) in that they utilize an unpredictable environment, by increasing rapidly to early maturing individuals which exist in dense populations. Consequently, either New Haven Harbor or Long Island Sound populations of these ubiquitous species should continue to provide larval populations to inhabit the New Haven intertidal areas each year. Unless new severe stresses occur in the Harbor, it appears that intertidal areas will continue to offer the same resources to tolerant colonists and subsequent foragers and predators with little or no consequence from operation of the New Haven Harbor Station.

SUMMARY

A total of 90 invertebrate taxa were collected from the intertidal area of New Haven Harbor over the seven-year sampling period. Dominant taxa were *Mya arenaria*, *Nereis succinea*, *Nereis* spp., *Gemma gemma*, *Ilyanassa obsoleta*, *Macoma balthica*, *Balanus improvisus*, *Spionidae*, *Limulus polyphemus*, and *Capitellidae*. Seasonal trends of increased species richness and abundance in October relative to May were apparent in most years. Greatest species richness and lowest annual variation occurred at Sandy Point: these parameters were reversed at East Shore. Except for the somewhat reduced faunal richness at inner harbor stations in 1976 (which subsequently increased), there were no events that suggested impact by plant operations. Hydrographic data show minimal, if any, impingement of the thermal plume on intertidal areas (Section 3.0).

7.0 LITERATURE CITED

- Anger, K. 1975. On the influence of sewage pollution on inshore benthic communities in South Kiel Bay. Part 2: Quantitative studies on community structure. *Helgolander Wiss. Meeresunter.* 27:408-438.
- Caspers, H. 1967. Estuaries: analysis of definitions and biological considerations. pp. 6-8 IN: *Estuaries* (ed.). G. H. Lauff. Publ. No. 83. AAAS, Washington, D.C.
- Connell, J. H. 1961. The influence of interspecific competition and other factors on the distribution of the barnacle *Cthamalus stellatus*. *Ecology*. 42:710-723.
- Connecticut State Department of Environmental Protection. 1977. Connecticut Water Quality Standards and Classifications.
- Cunningham. Unpublished report: Long Wharf flats.
- Daro, M. H. and P. Polk. 1973. The autecology of *Polydora ciliata* along the Belgian Coast. *Neth. J. Sea Res.* 6:130-140.
- Dayton, P. K. 1971. Competition, disturbance and community organization: the provision and subsequent utilization of space in a rocky intertidal community. *Ecol. Monogr.* 41:351-389.
- Dowe, R. L. and D. E. Wallace. 1957. The Maine Clam: *Mya arenaria*. Maine Department of Seas and Shore Fisheries Bull.
- Enright, J. T. 1977. Power plants and plankton. *Marine Pollution Bull.* 8(7):158-163.
- Grassle, J. F. and J. P. Grassle. 1974. Opportunistic life histories of genetic systems in marine benthic polychaetes. *J. Mar. Res.* 32:253-284.
- Hechtel, G. J. 1970. Biological effects of thermal effluents, Northport, New York. Part I: Intertidal benthic invertebrates. *Mar. Sci. Res. Cent., Stonybrook, Tech. Rep.*, p. 1-52.
- Jenner, C. E. 1957. Schooling behavior in mud snails in Barnstable Harbor leading to the formation of massive aggregations in a population of *Nassarius obsoletus*. *Biol. Bull.* 113:328-329.
- Naylor, E. 1965. Biological effects of a heated effluent in docks at Swansea, South Wales. *Zoo. Soc. Lond. Proc.* 144:253-268.
- Newcombe, C. L. 1935. Growth of *Mya arenaria* in the Bay of Fundy region. *Can. Jour. of Res.* Vol. 13, Sec. D(6):97-135.

- Normandeau Associates, Inc. 1971. Ecological considerations of the Coke Works Site, New Haven Harbor, Connecticut. Prepared for The United Illuminating Company, New Haven, Connecticut. 64 pp.
- _____. 1973a. New Haven Harbor Ecological Studies, New Haven, Connecticut. Annual Report, 1971-1972 for The United Illuminating Company, New Haven, Connecticut. 208 pp.
- _____. 1973b. Bridgeport Harbor Ecological Studies 1971-1972. Biological and Hydrographic Reports. Prepared for The United Illuminating Company. 196 pp.
- _____. 1974a. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report, 1972-1973 for The United Illuminating Company, New Haven, Connecticut. 215 pp.
- _____. 1974b. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Interim Report, May-December 1973 for The United Illuminating Company, New Haven, Connecticut. 199 pp.
- _____. 1974c. Stamford Harbor Ecological Studies, Final Report 1971-1973. Prepared for Northeast Utilities Service Company. 159 pp.
- _____. 1974d. Studies of Village Creek and other estuaries in the Norwalk, Connecticut area, August-October 1972. Prepared for the Connecticut Light and Power Company. 97 pp.
- _____. 1975. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1974 for The United Illuminating Company, New Haven, Connecticut. 223 pp.
- _____. 1976. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1975 for The United Illuminating Company, New Haven, Connecticut. 213 pp.
- _____. 1977. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1976 for The United Illuminating Company, New Haven, Connecticut. 376 pp.
- _____. 1978. New Haven Harbor Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1977 for The United Illuminating Company, New Haven, Connecticut. 359 pp.
- Paine, R. T. 1966. Food web complexity and species diversity. *Amer. Natur.* 100:65-75.
- Ropes, J. W. and A. P. Stickney. 1965. Reproductive cycle of *Mya arenaria* in New England. *Biol. Bull.* 128(2):315-327.
- Selmer, G. P. 1967. Functional morphology and ecological life history of the gem clam, *Gemma gemma*. *Malacologia.* 5:137-223.

- Shuster, C. N. 1950. Observations on the natural history of the American horseshoe crab, *Limulus polyphemus*. Third report on investigations of methods of improving the shellfish resources of Massachusetts, Contr. No. 564 WHOI. 18-23.
- Sibley, B. and D. Sibley. 1969. The intertidal invertebrates of Leetes Island and the Thimble Island region of Connecticut. Unpublished. 56 pp.
- TRIGOM-PARC. 1974. A socioeconomic and environmental inventory of the North Atlantic region. Prepared for Bureau of Land Management, Marine Minerals Division. 8 volumes. South Portland, Maine.
- Warriner, J. E. and M. L. Brehmer. 1966. The effects of thermal effluents on marine organisms. Air and Water Poll. 10:277-289.
- Wass, M. L. 1967. Biological and physiological basis of indicator organisms and communities. Section II: Indications of pollution. pp. 271-283 IN Pollution and Marine Ecology. T. A. Olson and F. J. Burgers. Interscience Publishers, New York.

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

8.0 EPIBENTHIC INVERTEBRATES

by Paul F. Ferreira, Jr., Kenneth A. Simon and Andrew J. McCusker

Normandeau Associates, Inc.
Bedford, N. H.

TABLE OF CONTENTS

	PAGE
<i>INTRODUCTION.</i>	8-1
<i>METHODS</i>	8-1
<i>CHARACTERIZATION OF NEW HAVEN HARBOR EPIBENTHIC INVERTEBRATE COMMUNITY</i>	8-6
<i>Selected Species.</i>	8-13
<i>ANALYSIS OF IMPACT.</i>	8-36
<i>LITERATURE CITED.</i>	8-46

LIST OF FIGURES

	PAGE
8-1. Epibenthic (otter trawl) samples collected through October 1977	8-21
8-2. Monthly abundance of <i>Crangon septemspinosa</i> collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977 . .	8-16
8-3. Percent of <i>Crangon</i> collected per size category in New Haven Harbor during various times of the year, from July 1976 through October 1977.	8-18
8-4. Monthly abundance of <i>Asterias forbesi</i> collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977	8-22
8-5. Monthly abundance of <i>Cancer irroratus</i> collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977	8-25
8-6. Distribution of <i>Cancer irroratus</i> by season in New Haven Harbor from 1974 through 1977.	8-26
8-7. Monthly abundance of <i>Ovalipes ocellatus</i> collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977	8-30
8-8. Monthly abundance of <i>Homarus americanus</i> collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977	8-32
8-9. Monthly abundance of <i>Squilla empusa</i> collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977	3-35

LIST OF TABLES

	PAGE
8-1. INVERTEBRATE FAUNA COLLECTED FROM EPIBENTHIC TRAWLS IN NEW HAVEN HARBOR, MAY 1971 THROUGH OCTOBER 1977. . . .	8-7
8-2. TOTAL ANNUAL ABUNDANCE, RANK OF ABUNDANCE AND EPIBENTHIC SPECIES RICHNESS BY STATION FROM JANUARY 1974 THROUGH OCTOBER 1977	8-9
8-3. ANNUAL ABUNDANCE BY STATION AND STATION RANK BY YEAR FOR THE TWELVE MOST COMMON EPIBENTHIC INVER- TEBRATES, JANUARY 1974 THROUGH OCTOBER 1977	8-12
8-4. RANK OF ABUNDANCE AND PERCENT OF TOTAL CATCH FOR SELECTED EPIBENTHIC SPECIES, 1974 THROUGH 1977. . . .	8-14
8-5. MEAN NUMBER OF EPIBENTHIC INVERTEBRATES IMPINGED PER 24 HOURS, MONTHLY, ON TRAVELING SCREENS OF THE NEW HAVEN HARBOR STATION COOLING WATER INTAKE SYSTEM. . .	8-44

8.0 EPIBENTHIC INVERTEBRATES

by Paul Ferreira, Jr., Kenneth Simon and Andrew McCusker
Normandeau Associates, Inc.
Bedford, N. H.

INTRODUCTION

Analysis of the invertebrate fauna collected as part of the demersal finfish trawling program supplied information on a segment of the benthic community that was not sampled in other monitoring programs. The mobility and relatively large size of most epibenthic invertebrate species are the prime reasons why they were not collected by other benthic sampling methods. Due in a large part to their mobility, epibenthic species sampled by trawling can be characterized by considerable spatial and temporal variability. Changes in distribution can, however, be related to seasonal movements, avoidance of environmental perturbations or stressful conditions, or attraction to a particular event or area. Monitoring of epibenthic species populations provides a data base to aid in detecting any major distributional or abundance changes that could be related to the New Haven Harbor Station operation.

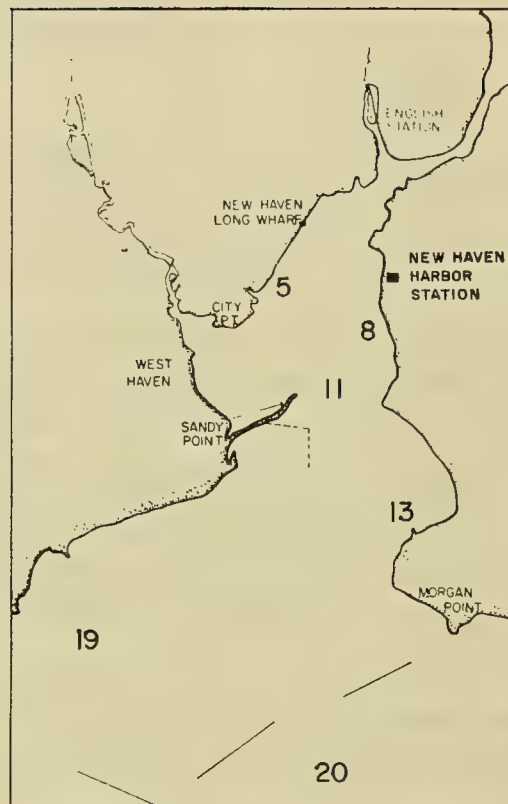
This report provides a comprehensive description of the New Haven Harbor epibenthic invertebrate community and assesses the impact of operation of the New Haven Harbor Station based on a review of all information available from the NHHSEMS data base. Six of the most commonly encountered invertebrate species are discussed in detail.

METHODS

Epibenthic sampling, designed for evaluation of epibenthic invertebrates and demersal fish populations, was conducted monthly at Stations 5, 8, 11, 13, 19 and 20 (Figure 8-1). Station 5, located at the shoal area midway between Long Wharf and the City Point sewer outfall, was established to supply data concerning the inner harbor epifaunal

Epibenthic (Otter Trawl) Sampling Stations

1971 STATIONS	5													
	8						x	x	x	x		x	x	x
	13						x	x	x		x	x		x
	19							x	x	x	x	x	x	x
	20						x	x	x	x	x	x	x	x
1972 STATIONS	5													
	8						x							x
	13						x	x	x	x	x	x	x	x
	19						x	x	x	x		x	x	x
	20						x	x	x	x	x	x	x	x
1973 STATIONS	5													
	8						x	x	x				x	x
	13						x	x	x	x	x	x	x	x
	19						x	x	x	x	x	x	x	x
	20						x	x	x	x	x	x	x	x
1974 STATIONS	5													
	8						x	x	x	x	x	x	x	x
	13						x	x	x	x	x	x	x	x
	19						x	x	x	x	x	x	x	x
	20						x	x	x	x	x	x	x	x
							x	x	x	x	x	x	x	x
1975 STATIONS	5													
	8						x	x	x	x	x	x	x	x
	11													
	13						x	x	x	x	x	x	x	x
	19						x	x		x	x	x	x	x
	20						x	x	x	x	x	x	x	x
1976 STATIONS	5													
	8						x	x	x	x	x	x	x	x
	11						x	x	x	x	x	x	x	x
	13						x	x	x	x	x	x	x	x
	19						x	x	x	x	x	x	x	x
	20						x	x	x	x	x	x	x	x



1977 STATIONS		J	F	M	A	M	J	J	A	S	O
5		X	X	X	X	X	X	X	X	X	X
8		X	X	X	X	X	X	X	X	X	X
13		X	X	X	X	X	X	X	X	X	X
19		X	X	X	X	X	X	X	X	X	X
20		X	X	X	X	X	X	X	X	X	X

Figure 8-1. Epibenthic (otter trawl) samples collected through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

assemblages. Located in the main channel directly off the New Haven Harbor Station site, Station 8 is most proximal to the New Haven Harbor Station thermal discharge and would be expected to have the greatest potential for experiencing direct effects of the discharge. Station 11, located in the main channel off Fort Hale Park and considered representative of the middle-harbor area, was added to the epibenthic program in May 1975 to serve as a field control because of its similarities to Station 8 in terms of depth, bottom substrate, and water quality. The outer harbor stations, which would be expected to be least directly influenced by either the thermal plume or any general warming of the water, include the southern part of Morris Cove, Station 13; the shoal area off Savin Rock, Station 19; and the main channel outside the harbor breakwaters, Station 20.

Sampling was conducted monthly from May 1971 through October 1977 (Figure 8-1). Due to severe ice-cover conditions in the harbor, January 1977 was the only month in which no sampling was conducted. Epibenthic collections were made using a 25-ft Marinovich semi-balloon otter trawl constructed with a 1-3/8-inch stretch-mesh body and wings, and fitted with a 1/4-inch "Ace" knotless cod-end liner.

Several changes in sampling design were made during the monitoring program. Initially, single tows, 15 minutes in duration, at approximately 1-2 kn against the tide were taken at each station from May 1971 through December 1973. Tow duration was reduced to 10 minutes in January 1974. During May and June 1975 the single 10-minute tow was replaced by duplicate 5-minute tows in an attempt to upgrade the quality of sampling in the epibenthic invertebrate and demersal finfish program. Evaluation of May and June 1975 data led to a final design (used from July 1975 through October 1977) of duplicate 10-minute tows. In order to maintain consistency with preoperational data, analyses in this report are based on data from the first tow rather than a composite of both tows. Data from the second tow were used to subjectively confirm the reliability of data from the first tow.

/

The fifteen-minute tows utilized through December 1973 represent a considerably larger area sampled in comparison to the 10-minute tows utilized during the remainder of the program. For this reason data prior to 1974 cannot be used to make quantitative comparisons with the 1974 through 1977 data base. It can, however, be used qualitatively in comparing spatial and temporal trends in species relative abundance. Data collected as part of the 5-minute duplicate tows utilized during May and June 1975 must also be viewed with caution; however, in this case, data from the duplicate tows were combined, thus approximating a single 10-minute tow. Data collected from the duplicate 10-minute trawls utilized July 1975 through October 1977 can be used to make quantitative comparisons with data obtained from single 10-minute trawls used January 1974 through April 1975 since only the first tow was used for data analyses.

Organisms collected in the trawls were identified and counted in the field. In addition, beginning in July 1976, length and weight (wet) data were collected for several of the more important species. Crustaceans were weighed and sexed, and gravid females noted. Size measurements were taken as follows: crabs were measured for greatest carapace width; sand shrimp for total length; and lobsters for both total length and carapace length. Starfish were weighed and greatest diameter measured.

When large numbers (several hundred individuals) of a species were collected, counts were based on a subsample of the total. The size of the subsample varied with the individual species; in general, 25 individuals were used for a subsample and total count was estimated on the basis of the weight of the subsample compared to the total weight of the individuals. In the case of small, highly abundant species such as the sand shrimp, ten 100-ml subsamples were counted to arrive at the total estimated count. From July 1975 through October 1977, when duplicate 10-minute trawls were used, the contents of both tows were identified and counted. At each station and sample period, length and weight data were collected for organisms in the first tow; organisms in the

second tow were measured only when composition of the tows were determined subjectively to be dissimilar or if considerably fewer individuals of a given species were collected in the first tow.

Impingement data collected by United Illuminating Company personnel have been used to provide additional information on the epibenthic community, particularly in terms of seasonal abundance patterns as well as a basis for consideration of the potential impact of the New Haven Harbor Station operation on the epibenthic community. Impingement data are presented as the average number of organisms impinged per 24 hours, monthly from August 1975 through October 1977.

Data acquired as part of monitoring programs for other utilities in Long Island Sound have been used as a basis for comparison of New Haven Harbor with other Long Island Sound sites. The Stamford Harbor Ecological Studies (NAI, 1974) conducted for the Northeast Utilities Service Company supply epibenthic invertebrate data for Stamford Harbor from April 1971 through October 1973. The same otter trawl as was used in the New Haven program was utilized in Stamford, and tow duration (15 minutes) was the same as in the 1971 through 1973 NHHSEMS (NAI, 1972, 1973, 1974) epibenthic sampling. Sampling was conducted monthly from April 1971 through December 1972 and bimonthly through October 1973. All months but January were sampled at least once. Monthly catch per unit effort as well as seasonal and annual averages for the seven most abundant invertebrate species is presented in the Stamford Harbor report.

Epibenthic surveys at Shoreham and Port Jefferson, Long Island, are not directly comparable to NHHSEMS data because of the difference in sampling techniques. However, these data are useful in making qualitative comparisons of seasonal trends. Sampling was conducted using lobster pots and whelk traps at Shoreham; and lobster, crab and whelk pots, clam rakes, and bottom grabs at Port Jefferson.

Impingement programs conducted in conjunction with monitoring programs for various Long Island Sound power plants provide information

on abundances, size and seasonality of impinged epibenthic invertebrates. In addition to New Haven Harbor Station, impingement data are available for Millstone Nuclear Power Station, Waterford, Connecticut; Bridgeport Harbor Station, Bridgeport Harbor; Devon Station, Housatonic River; Middletown Station, Connecticut River; Montville Station, Thames River estuary; Norwalk Harbor Station, Norwalk Harbor; Northport Station, Northport, Long Island; Port Jefferson Station, Port Jefferson, Long Island and Glenwood Station, Glenwood, Long Island. Data from these stations have been used to qualify observations made in New Haven Harbor and they provide input into evaluation of seasonal movements of migratory species.

CHARACTERIZATION OF NEW HAVEN HARBOR EPIBENTHIC INVERTEBRATE COMMUNITY

During the course of the New Haven Harbor Station Ecological Monitoring Studies, 44 epibenthic invertebrate taxa were collected (Table 8-1). Fourteen taxa were common to all years of the program (1971-1977); an additional six were encountered during all of the last five years of the study (1973-1977) (Table 8-1). The total number of epibenthic taxa collected yearly did not vary substantially. Maximum numbers of taxa were collected during 1972 (28 taxa) and 1977 (27 taxa), while the least numbers were observed in 1975 and 1976 (24 taxa each year) (Table 8-1). Largely as a result of variations in the abundance of *Crangon*, total annual abundance varied substantially from year to year. Highest annual abundances of all species were observed during 1975 (114,000 individuals) and 1977 (112,000 individuals) while lowest abundances occurred during 1974 (56,000 individuals) and 1976 (76,000 individuals) (Table 8-2). The 1-3/8" mesh on the wings and body of the otter trawl is actually too large to effectively sample *Crangon*. By comparison of duplicate tows, however, it can be seen that reasonably comparable numbers are collected and therefore *Crangon* abundance estimates are included.

The distribution of epibenthic invertebrates in New Haven Harbor is governed by a number of factors, including: sediment type,

TABLE 8-1.

INVERTEBRATE FAUNA COLLECTED FROM EPIBENTHIC TRAWLS IN
NEW HAVEN HARBOR, MAY 1971 THROUGH OCTOBER 1977. NEW
HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

SPECIES	MAY-DEC 1971	JAN-DEC 1972	JAN-DEC 1973	JAN-DEC 1974	JAN-DEC 1975	JAN-DEC 1976	FEB-OCT 1977
<i>Aequipecten irradians</i>	x						
* <i>Anemone</i> unidentified	x	-					
<i>Arbacia punctulata</i>		x					
* <i>Astarte undata</i>							x
<i>Asterias forbesi</i>	x	x	x	x	x	x	x
<i>Asterias vulgaris</i>	x						
<i>Asterias</i> sp.	x	x	x				
* <i>Astrangia danae</i>							x
* <i>Balanus balanoides</i>	x		x				
* <i>Balanus eburneus</i>	x						
* <i>Balanus improvisus</i>	x						
* <i>Balanus</i> sp.			x				x
<i>Busycon canaliculatum</i>		x	x	x	x	x	x
<i>Busycon carica</i>							x
*Bryozoa							x
<i>Callinectes sapidus</i>		x	x	x	x	x	x
<i>Cancer irroratus</i>	x	x	x	x	x	x	x
<i>Cancer</i> sp.	x	x					
<i>Carcinus maenas</i>		x	x	x	x	x	x
* <i>Chalina</i> sp.					x		
* <i>Chalina oculata</i>							x
* <i>Cirolana concharum</i>							x
* <i>Cliona celata</i>	x			x			
* <i>Cliona</i> sp.		x				x	x
<i>Crangon septemspinosa</i>	x	x	x	x	x	x	x
<i>Crangon vulgaris</i>	x						
<i>Crassostrea virginica</i>	x	x	x	x	x	x	x
<i>Crepidula fornicata</i>	x	x	x	x	x	x	x
<i>Crepidula plana</i>	x	x	x	x	x	x	x
<i>Crepidula convexa</i>			x				
*Ctenophore				x	x	x	x
* <i>Cyanea capillata</i>					x	x	
* <i>Cyanea</i> sp.							x
* <i>Ensis directus</i>		x	x				
<i>Eupleura caudata</i>				x			
<i>Haminoea solitaria</i>							x
* <i>Hymeniacion</i> sp.					x		
<i>Homarus americanus</i>	x	x	x	x	x	x	x
<i>Ilyanassa obsoleta</i>	x	x	x	x	x	x	x
* <i>Illex illecebrosus</i>			x				
* <i>Lepidonotus squamatus</i>	x						
<i>Libinia dubia</i>					x	x	
<i>Libinia emarginata</i>		x			x	x	x
<i>Libinia</i> sp.	x	x	x	x			

Continued

TABLE 8-1. (Continued)

SPECIES	MAY-DEC 1971	JAN-DEC 1972	JAN-DEC 1973	JAN-DEC 1974	JAN-DEC 1975	JAN-DEC 1976	FEB-OCT 1977
<i>Limulus polyphemus</i>	x	x	x	x	x	x	x
* <i>Loligo pealei</i>		x		x	x	x	x
<i>Lunatia heros</i>	x	x					x
* <i>Mercenaria mercenaria</i>	x	x	x	x		x	x
* <i>Metridium senile</i>							x
* <i>Metridium</i> sp.	x	x	x		x		
* <i>Microciona prolifera</i>	x	x		x	x		x
* <i>Modiolus modiolus</i>							x
* <i>Mogula manhattensis</i>						x	
* <i>Mogula</i> sp.						x	x
* <i>Mulinia lateralis</i>						x	x
* <i>Mya arenaria</i>							x
<i>Mysis</i> sp.	x						
* <i>Mytilus edulis</i>					x	x	x
<i>Nassarius trivittata</i>	x	x	x	x	x	x	x
<i>Nassarius</i> sp.		x					
<i>Neopanope sayi</i>	x	x	x	x	x	x	x
* <i>Nereis</i> sp.			x				
* <i>Nucula</i> sp.						x	
* <i>Obelia</i> sp.				x			
<i>Ovalipes ocellatus</i>	x	x	x	x	x	x	x
<i>Ovalipes</i> sp.	x	x					
<i>Pagurus longicarpus</i>	x	x	x	x	x	x	x
<i>Pagurus pollicaris</i>		x	x	x	x	x	x
<i>Pagurus</i> sp.	x		x				
<i>Palaemonetes</i> sp.					x	x	
<i>Palaemonetes vulgaris</i>	x			x			x
<i>Panopeus herbstii</i>	x	x					x
<i>Penaeus aztecus</i>				x	x		x
* <i>Pitar morrhuana</i>				x	x		
<i>Polinices duplicata</i>	x	x	x	x	x	x	x
<i>Polinices heros</i>				x		x	
<i>Retusa obtusa</i>			x				
<i>Squilla empusa</i>			x	x	x	x	x
* <i>Tellina</i> sp.			x				
* <i>Thuiaria robusta</i>						x	
* <i>Thyone briareus</i>							x
<i>Urosalpinx cinerea</i>		x	x	x	x	x	x
* <i>Yoldia limatula</i>							x
Total number of taxa collected	35	34	33	32	34	35	47
Total number of Epi-benthic taxa collected	26	28	26	25	24	24	27

* Individuals collected in trawl but not counted as part of the total number of epibenthic species.

TABLE 8-2. TOTAL ANNUAL ABUNDANCE, RANK OF ABUNDANCE* AND EPIBENTHIC SPECIES RICHNESS BY STATION FROM JANUARY 1974 THROUGH OCTOBER 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

S T A T I O N S

	YEAR	5	8	11**	13	19	20	TOTAL
Total all species	1974	9,251	25,622	NS	11,296	5,031	4,675	55,875
	1975	28,991	35,203	36,421	8,960	2,019	2,510	114,104
	1976	17,174	14,625	16,840	13,352	11,010	3,061	76,074
	1977 +	23,381	46,782	29,283	10,062	1,528	3,945	114,981
Total Epibenthic Species	1974	9,251	25,622	NS	11,296	5,031	4,648	55,848
	1975	28,991	35,203	36,421	8,960	2,019	2,510	114,104
	1976	17,174	14,617	16,814	13,350	10,922	2,850	75,939
	1977	23,320	46,771	29,276	10,052	1,506	1,113	112,038
Station Rank of Abundance* for Total Epibenthic Species	1974	3	1	NS	2	4	5	
	1975	2	1	1	3	5	4	
	1976	1	2	2	3	4	5	
	1977	2	1	2	3	4	5	
Epibenthic Species Richness	1974	17	18	NS	17	17	17	25
	1975	16	15	14	18	17	16	24
	1976	17	17	19	18	18	18	24
	1977	16	20	18	19	17	19	27

* Station 11 not included in ranking in order to maintain continuity in station rank between preoperational and operational years. The value indicated is the rank for Station 11 had it been ranked with the other stations.

** Total of 8 months sampling at Station 11 during 1975

† Total of 9 months sampling during 1977 for all stations

temperature, salinity, and dissolved oxygen, as well as biological factors such as available food source, predator-prey relations, and interspecific and intraspecific competition for available habitat resources. As is the case in most estuarine systems, physical and chemical parameters varied from one area to another resulting in differences in species composition and relative abundances. In New Haven Harbor, low salinities in the inner harbor, particularly during winter and spring, restrict many stenohaline species such as the common starfish, *Asterias forbesi*, from the area. In contrast, euryhaline species such as *Palaemonetes vulgaris*, a caridean shrimp, and the mud snail, *Ilyanassa obsoleta* can tolerate fluctuating salinities and are abundant in this area. The inner harbor is characteristically a highly variable environment. Physical/chemical parameters such as temperature, dissolved oxygen and salinity fluctuate widely. During summer, dissolved oxygen drops considerably (4.0 ppm and lower) and temperatures are high (22-24°C). During winter the opposite occurs: temperatures may drop to near freezing and dissolved oxygen increases to supersaturation levels. As a result, many organisms move in and out of the area in response to the changing environmental conditions, and species composition and abundances fluctuate widely over the course of a year.

Inner harbor Station 5 has consistently ranked among the top three stations in annual abundance (Table 8-2). Characteristic epibenthic species in this area have been *Crangon septemspinosa*, *Ilyanassa obsoleta*, *Limulus polyphemus* and *Palaemonetes vulgaris*, and to a lesser degree, *Nassarius trivittatus* and *Ovalipes ocellatus* (NAI, 1978a).

The epibenthic invertebrate community in the deeper water of the main shipping channel in the vicinity of the Harbor Station discharge (Station 8) and middle harbor (Station 11) was composed of a somewhat different array of epifaunal species (NAI, 1975a, 1976a, 1977 and 1978a). Both stations were similar in terms of species composition and abundance, and typically ranked either first or second in total annual abundance (Table 8-2). Salinity at these areas does not fluctuate to as large a degree as at Station 5. Bottom dissolved oxygen

does reach low levels during July, August and September, but not to the degree and duration observed at Station 5 (Section 3.0). Stations 8 and 11, particularly along the edges of the shipping channel, consist largely of black/grey marine mud (NAI, 1972) which is cohesive enough to allow several types of organisms to burrow into it for shelter. Lobsters, mantis shrimp and sand shrimp, all of which are burrowers, were found in high abundances in these areas (Table 8-3). The benthic infauna, consisting primarily of polychaetes, oligochaetes and molluscs, was occasionally abundant in this area (NAI, 1978a) and the sediments contained much detritus. As a result, predatory species such as *Asterias forbesi*, *Lunatia heros*, *Polinices duplicata*, *Neopanope sayi*, *Pagurus longicarpus*, and to a lesser degree, *Cancer irroratus*, have an ample food supply and are common to the area.

In the outer harbor area, fluctuations in salinity, temperature and dissolved oxygen are reduced due to increased Long Island Sound influence and decreased freshwater influence from the three main tributaries to New Haven Harbor. As a result, certain species which were absent or collected in low abundances in the inner harbor were collected in high abundances in the outer harbor. Principal species in this category were *Cancer irroratus*, *Pagurus pollicaris* and *Libinia emarginata*. Lobsters, mantis shrimp and sand shrimp were taken in lesser abundances in the outer harbor -- possibly as a result of differences in the sediment composition. Since lobsters readily establish shelter in rocky habitats that are not conducive to trawling, it is deemed probable that their abundance in the outer harbor amongst the rocky outcrops and harbor breakwaters was greater than indicated by outer harbor trawl data; the abundance of lobster traps in the vicinity of the breakwaters and adjacent hard-bottom areas supports this conclusion (NAI, 1977).

Many epibenthic invertebrates in New Haven Harbor undergo seasonal changes in abundance apparently related to changes in water temperature and possibly dissolved oxygen. In general, abundance was highest during periods of moderate water temperatures - i.e., late spring to early summer and fall; it was lowest during periods of extreme

TABLE 8-3. ANNUAL ABUNDANCE BY STATION AND STATION RANK BY YEAR* (IN PARENTHESES) FOR THE TWELVE MOST COMMON EPIBENTHIC INVERTEBRATES, JANUARY 1974 THROUGH OCTOBER 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

SPECIES	YEAR	5	8	11**	13	19	20	TOTAL
<i>Crangon septemspinosa</i>	1974	5,222 (2)	20,161 (1)	NS	1,408 (5)	2,354 (3)	1,926 (4)	31,071
	1975	27,746 (2)	33,103 (1)	34,825 (1)	4,062 (3)	716 (4)	677 (5)	101,129
	1976	15,191 (1)	13,778 (2)	15,482 (1)	12,045 (3)	9,903 (4)	1,957 (5)	68,356
	1977 +	10,870 (2)	46,138 (1)	28,375 (2)	6,878 (3)	453 (5)	676 (4)	93,390
<i>Asterias forbesi</i>	1974	215 (5)	5,078 (2)	NS	9,450 (1)	1,446 (3)	922 (4)	17,111
	1975	520 (4)	1,841 (2)	1,001 (3)	3,199 (1)	776 (3)	436 (5)	7,773
	1976	99 (5)	429 (2)	946 (1)	646 (1)	221 (4)	310 (3)	2,651
	1977	28 (5)	91 (3)	221 (1)	125 (1)	65 (4)	99 (2)	629
<i>Cancer irroratus</i>	1974	120 (4)	150 (3)	NS	83 (5)	830 (2)	1,264 (1)	2,447
	1975	86 (3)	54 (5)	106 (3)	157 (2)	56 (4)	234 (1)	693
	1976	48 (5)	91 (4)	66 (5)	122 (3)	235 (1)	174 (2)	736
	1977	56 (5)	122 (4)	175 (3)	279 (3)	611 (1)	135 (2)	1,378
<i>Ovalipes ocellatus</i>	1974	30 (1)	11 (2)	NS	19 (3)	0 (5)	2 (4)	62
	1975	191 (2)	27 (3)	60 (3)	1,156 (1)	0 (5)	4 (4)	1,438
	1976	11 (4)	13 (3)	57 (2)	80 (1)	9 (5)	37 (2)	207
	1977	125 (3)	196 (2)	267 (2)	2,599 (1)	14 (5)	19 (4)	3,220
<i>Ilyanassa obsoleta</i>	1974	2,959 (1)	4 (2)	NS	0 (4)	0 (4)	1 (3)	2,964
	1975	223 (1)	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)	223
	1976	1,605 (1)	0 (4)	1 (3)	0 (4)	3 (2)	1 (3)	1,610
	1977	94 (1)	1 (2)	1 (2)	0 (3)	0 (3)	0 (3)	96
<i>Pagurus longicarpus</i>	1974	4 (5)	25 (3)	NS	255 (1)	186 (2)	24 (4)	494
	1975	29 (5)	37 (4)	227 (2)	261 (1)	194 (2)	61 (3)	809
	1976	36 (5)	40 (4)	50 (4)	268 (1)	143 (2)	99 (3)	636
	1977	73 (3)	35 (5)	35 (5)	107 (2)	194 (1)	70 (4)	514
<i>Nassarius trivittata</i>	1974	609 (1)	87 (2)	NS	21 (4)	75 (3)	16 (5)	808
	1975	6 (3)	1 (5)	1 (5)	7 (2)	30 (1)	2 (4)	47
	1976	29 (2)	27 (3)	27 (3)	13 (5)	78 (1)	20 (4)	194
	1977	1 (3)	2 (2)	0 (4)	1 (3)	1 (3)	5 (1)	10
<i>Squilla empusa</i>	1974	0 (3)	18 (1)	NS	1 (2)	0 (3)	0 (3)	19
	1975	18 (2)	62 (1)	57 (2)	2 (4)	11 (3)	0 (5)	150
	1976	73 (3)	114 (1)	107 (3)	14 (5)	115 (2)	23 (4)	446
	1977	9 (4)	89 (1)	66 (2)	15 (2)	14 (3)	1 (5)	194
<i>Libinia emarginata</i>	1974	0 (4)	1 (3)	NS	0 (4)	3 (2)	265 (1)	269
	1975	0 (5)	10 (4)	4 (5)	29 (2)	52 (1)	20 (3)	115
	1976	15 (4)	16 (3)	22 (2)	2 (5)	89 (1)	17 (2)	161
	1977	3 (5)	4 (4)	7 (3)	6 (3)	16 (1)	9 (2)	45
<i>Homarus americanus</i>	1974	3 (3)	59 (1)	NS	19 (2)	2 (4)	2 (4)	85
	1975	5 (3)	44 (1)	90 (1)	17 (2)	2 (4)	0 (5)	158
	1976	2 (4)	45 (1)	31 (2)	24 (2)	11 (3)	2 (5)	114
	1977	1 (5)	52 (1)	61 (1)	8 (2)	6 (3)	2 (4)	130
<i>Neopanope sayi</i>	1974	3 (4)	10 (3)	NS	13 (2)	2 (5)	27 (1)	55
	1975	2 (5)	7 (3)	3 (4)	3 (4)	27 (1)	24 (2)	66
	1976	5 (5)	16 (3)	15 (4)	43 (2)	7 (4)	75 (1)	161
	1977	13 (4)	16 (2)	25 (2)	14 (3)	5 (5)	26 (1)	99
<i>Pagurus pollicaris</i>	1974	0 (3)	0 (3)	NS	3 (2)	6 (1)	0 (3)	9
	1975	0 (4)	0 (4)	2 (3)	2 (3)	7 (2)	39 (1)	50
	1976	0 (5)	1 (4)	1 (4)	3 (3)	37 (2)	90 (1)	132
	1977	0 (5)	1 (4)	20 (3)	4 (3)	106 (1)	54 (2)	185

* Station 11 not included in ranking in order to maintain continuity in station rank between preoperational and operational years. The value indicated is the rank for Station 11 had it been ranked with the other stations.

** Total of 8 months sampling at Station 11 during 1975.

+ Total of 9 months sampling during 1977 for all stations.

water temperature - i.e., winter and more notably mid-summer. Seasonal abundance patterns as judged from sampling may also have reflected local inshore-offshore movements or changing degrees of activity. In the section to follow ("Selected Species"), detailed consideration is given to six commonly encountered epibenthic species, with consideration of their seasonal and annual abundance patterns, and distribution.

Other epibenthic species inhabit New Haven Harbor waters but are collected in abundances too low to accurately characterize their individual distribution or abundance patterns. Included in this category are: *Busycon canaliculatum*, the channeled whelk; *Nassarius trivittatus*, a mud snail common intertidally on mud flats; the oyster-drill, *Urosalpinx cinerea*; the commercially important blue crab, *Callinectes sapidus*; the green crab, *Carcinus maenas*; the mud crabs, *Neopanope sayi* and *Panopeus herbstii*; *Limulus polyphemus*, the horseshoe crab; and the moon-snails *Lunatia heros* and *Polinices duplicata*, both predacious carnivores that feed on other molluscs. Many of these species were not quantitatively collected by otter trawls either because of their size or because their preferred habitat is not conducive to bottom trawling.

Selected Species

Crangon septemspinosus

The numerically dominant epibenthic invertebrate in New Haven Harbor was the caridean shrimp, *Crangon septemspinosus*. The sand shrimp, *Crangon*, consistently ranked first in abundance, comprising from 56 to 90 percent of the total annual catch (Table 8-4). *Crangon* forms an integral part of the food web in New Haven Harbor; considered a scavenger and secondary consumer, it feeds on organic detritus, small polychaetes, and benthic and planktonic crustaceans (Price, 1962; Regnault, 1976). In turn, *Crangon* forms an important food source for many finfish species such as flounder, weakfish, bluefish, skates and rays (Bigelow and Schroeder, 1953, and Price, 1962). In the western North Atlantic, *Crangon* ranges from Baffin Bay to east Florida (Williams, 1965).

TABLE 8-4. RANK OF ABUNDANCE AND PERCENT OF TOTAL CATCH FOR SELECTED EPIBENTHIC SPECIES, 1974 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

SPECIES	1974-1977	1977		1976		1975		1974	
	RANK	RANK	% ¹	RANK	% ¹	RANK	% ¹	RANK	% ¹
<i>Crangon septemspinosa</i>	1	1	81.0	1	89.8	1	88.6	1	55.6
<i>Asterias forbesi</i>	2	5	0.6	2	3.5	2	6.8	2	25.2
<i>Cancer irroratus</i>	3	4	1.2	4	1.0	6	0.6	4	4.4
<i>Ovalipes ocellatus</i>	4	3	2.8	8	0.3	3	1.3	11	0.1
<i>Ilyanassa obsoleta</i>	5	11	<0.1	3	2.0	7	0.2	3	5.3
<i>Pagurus longicarpus</i>	6	6	0.5	5	0.8	5	0.7	6	0.9
<i>Nassarius trivittata</i>	7	17	<0.1	9	0.3	15	<0.1	5	1.4
<i>Squilla empusa</i>	8	7	0.2	6	0.6	9	0.1	17	<0.1
<i>Libinia emarginata</i>	9	12	<0.1	10	0.2	10	0.1	7	0.5
<i>Homarus americanus</i>	10	9	0.1	13	0.1	8	0.1	10	0.1
<i>Neopanope sayi</i>	11	10	<0.1	10	0.2	12	<0.1	12	0.1
<i>Pagurus pollicaris</i>	12	8	0.2	11	0.2	14	<0.1	15	<0.1

1

Percent of total annual catch

In New Haven Harbor *Crangon* was collected most abundantly at the inner and middle harbor stations and least abundantly in the outer harbor (Stations 19 and 20) (Table 8-3). Total annual abundance of this species has fluctuated, with highest numbers found during 1975 (101,000 individuals) and the 9-month survey of 1977 (93,000 individuals), while lowest abundances were observed during 1974 (31,000 individuals) and 1976 (68,000 individuals) (Table 8-3). Variability in catch-abundance was also evident on a monthly basis; however, no clearly defined seasonal pattern was observed (Figure 8-2). In the outer harbor (Stations 19 and 20), where *Crangon* abundances were low, a trend of decreasing abundance during summer and early fall was apparent. However, no such trends were apparent at inner and middle harbor stations where abundances and variability in abundance was high. In New Haven Harbor, variations in abundance between months and stations were as high as four orders of magnitude, indicating the extreme spatial patchiness of the *Crangon* population. In a study of the benthic epifauna of Long Island Sound, Richards and Riley (1967) similarly found the abundance of *Crangon* to be highly variable due to patchiness, thus obscuring seasonal abundance patterns.

Variability in the abundance data of *Crangon* is to some degree a result of the inability of the trawl to quantitatively sample this species. Under normal circumstances the 1-3/8-inch mesh of the trawl's wings and body is too large to effectively sample small individuals. Clogging of the trawl, however, can increase the number of small individuals collected, thereby providing an additional source of variability in the abundance data. Variability in the abundance of *Crangon* may also be attributed to its mode of existence. *Crangon* utilizes both infaunal and epifaunal habitats, spending much time foraging on the bottom and occasionally among the plankton, while at other times burrowing into the bottom sediments (Price, 1962). Such behavior can greatly affect the pattern of abundance as determined by epibenthic trawls. Epibenthic densities estimated from trawl data may not reflect actual densities since many individuals may be inhabiting burrows. Because of the observed similarity in catch abundance between duplicate tows, however,

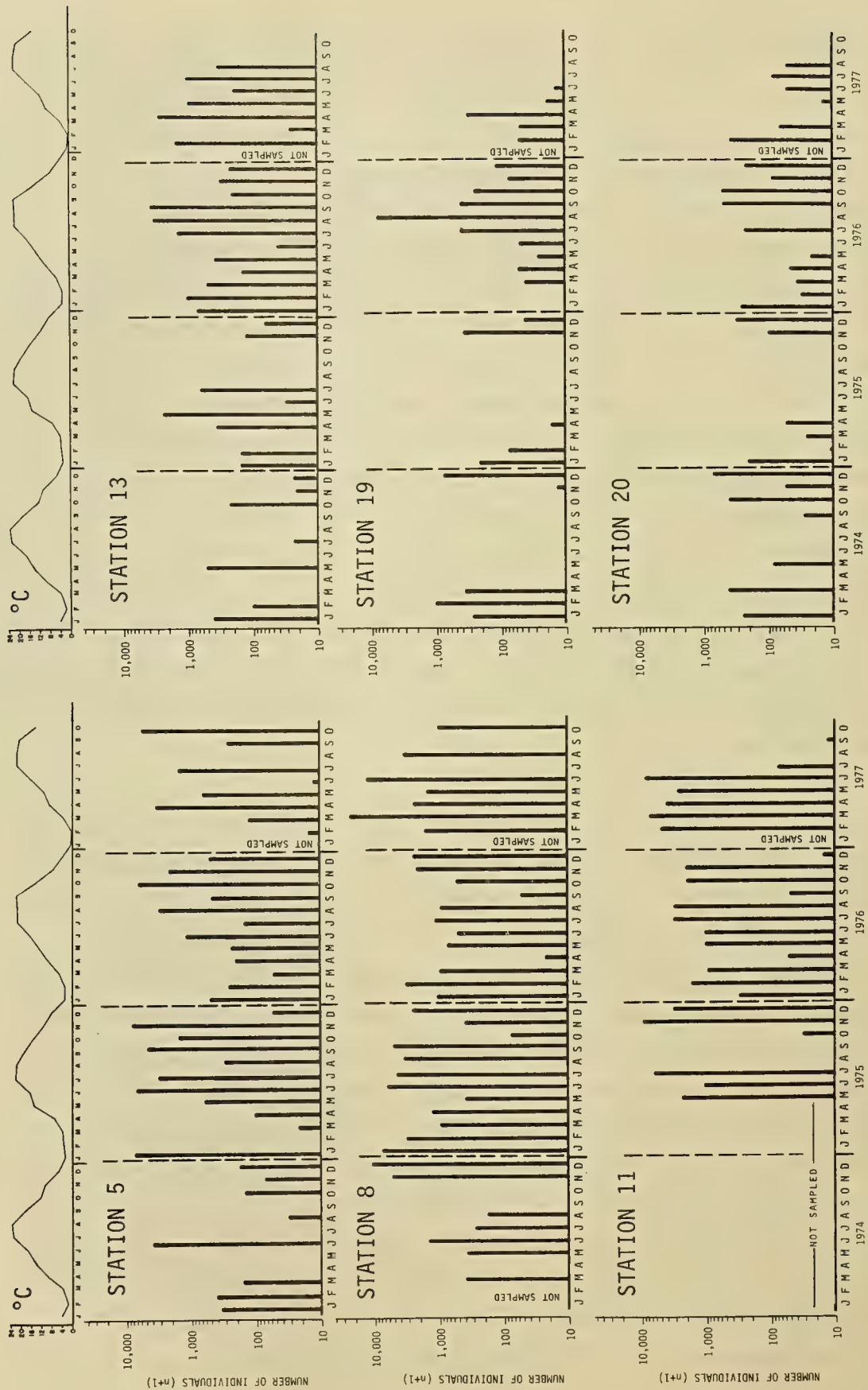


Figure 8-2. Monthly abundance of *Crangon septemspinosus* collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

abundance data can be used with some degree of quantitative validity, particularly in evaluating relative spatial and temporal trends in abundance.

Although catch-abundances of *Crangon* were variable, size distribution of *Crangon* populations in New Haven Harbor exhibited a measurable degree of seasonality with modal size increasing from fall through spring and decreasing during summer (Figure 8-3). From July through October 1976, 60% of the *Crangon* measured in trawl samples ranged in length from 21 to 30 mm with the 26-30 size-category containing the largest proportion of the catch. Modal size of *Crangon* increased from November 1976 through February 1977 when 60% of the individuals measured ranged in length from 26 to 40 mm and the 31 - 35 mm size-category contained the largest portion of the catch. During spring (March through June 1977) the modal size of *Crangon* continued to increase. During this period 60% of the individuals measured ranged in length from 31 to 45 mm and the 41 to 45 size-category contained the largest portion of the catch. During summer and early fall (July-October 1977) the modal length of *Crangon* decreased. As in 1976, 60% of the individuals measured ranged in length from 21 to 30mm and the 26-30 size-category contained the largest portion of the catch. This decrease in population size was attributable to both a large decrease in the number of shrimp in the larger size-categories as well as an increase in the number of shrimp in the smaller size-categories.

In New Haven Harbor, it is not certain whether adult shrimp migrate from the harbor during summer or whether they are simply exposed to an elevated level of predation once having reached a certain size (maximum size of *C. septemspinosus* is approximately 70mm; Price, 1962; NAI, 1978a). Price (1962) observed a similar seasonality of size-distribution of *Crangon* in Delaware Bay; highest abundance of sand shrimp was observed during spring with largest individuals also collected during this period. Three year-classes of females and two year-classes of males inhabit the waters of Delaware Bay during spring; during summer, the oldest year-classes of both sexes disappear from the

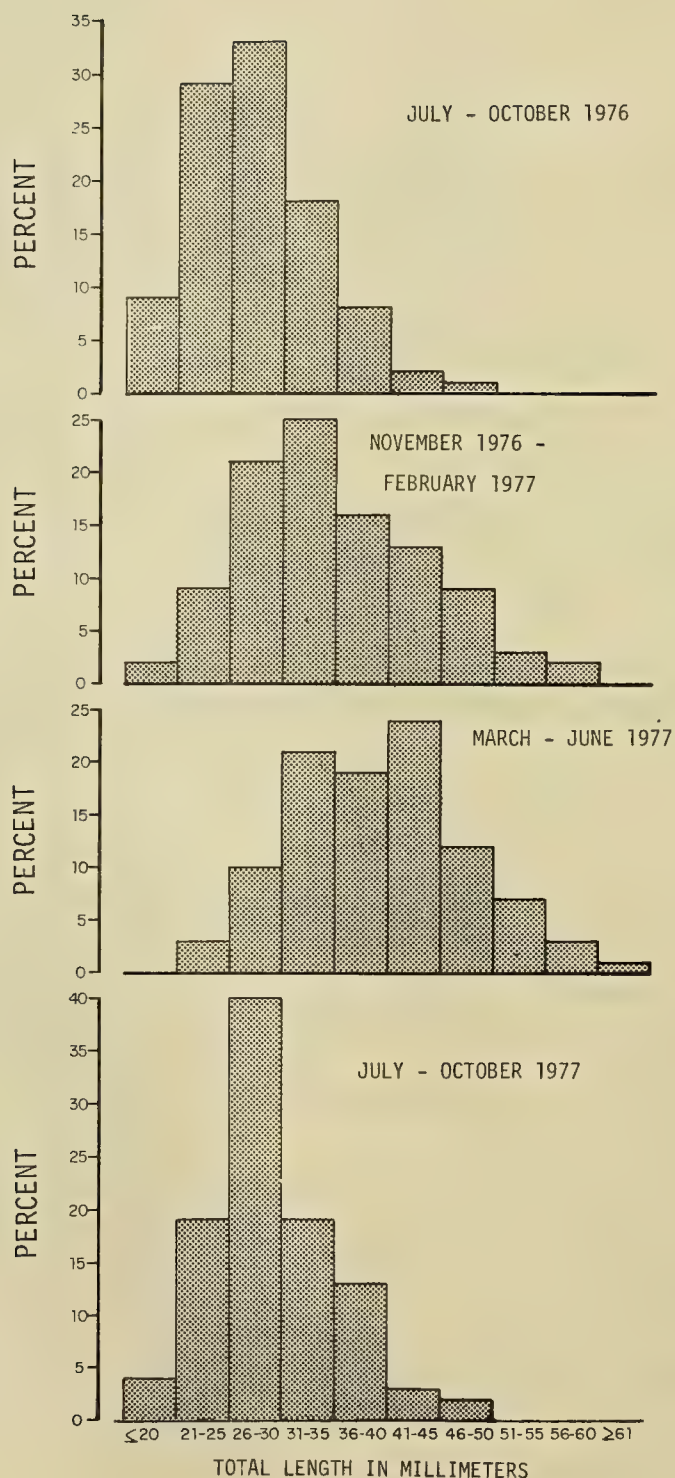


Figure 8-3. Percent of *Crangon* collected per size category in New Haven Harbor during various times of the year, from July 1976 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

area. As a result, mean lengths and abundances decreased in Delaware Bay from spring to late summer. Price was not certain whether this was due to increased predation or migration, but he suggested that *Crangon* undergoes a seasonal change in spawning grounds from inshore waters to deeper offshore waters. Seasonal migrations are also documented for *Crangon septemspinosa* in estuaries near Beaufort, North Carolina; here shrimp move offshore beginning in July and August and return the following winter and spring (Williams, 1965).

Seasonal migrations of the European brown shrimp, *Crangon crangon*, in European waters are well documented (Boddeke, 1975 and 1976). Adult shrimp were observed to undergo local inshore-offshore movements. Shoreward movement was observed during the spring with gravid females the first to move in followed by adult males; emigration of adults, including sexually ripe shrimp, occurred during the fall. Juvenile shrimp did not migrate to the extent of adults and usually remained in coastal waters year round (Boddeke, 1976).

In New Haven Harbor, size-data for *Crangon septemspinosa* suggest that adult shrimp migrate into the harbor during spring and peak in abundance during May and June which would explain the gradual increase in the modal size of shrimp during this period. During summer, increasing temperatures and possibly decreasing dissolved oxygen levels may act to stimulate emigration of adults from the harbor to deeper waters. Since juveniles do not migrate to the extent of adults (Boddeke, 1976; Price, 1962), modal size-distribution observed during the summer would reflect a predominantly juvenile population. Also, since the number of small shrimp collected during the summer tends to increase - possibly as a result of growth to catchable size from the previous years' spawning - migration of adult shrimp is not apparent in the abundance data. During winter and spring, a gradual return of adult shrimp occurs with a resulting increase in modal size. Observations by Richards and Riley (1967) on the benthic epifauna of Long Island Sound further supports this conclusion; they found that the standing crop of *Crangon* in Long Island Sound increased during late summer. This may reflect movement of adult sand shrimp from inshore waters to the deeper waters of Long Island Sound during this period.

Asterias forbesi

The common starfish, *Asterias forbesi*, has been the second most abundant species collected in epibenthic trawls. It ranges from Cape Cod Bay to Cape Hatteras and is common from the littoral zone to approximately 49 m (Gosner, 1971). *Asterias*, although primarily a predator of bivalve molluscs, will consume fish or almost any other organisms that it can capture. Hardy (1965) indicated that starfish in general are perhaps the most voracious of the invertebrate carnivores. During the period 1966 to 1969 the starfish, *Asterias forbesi*, was cited as the most important cause of oyster mortality in Long Island Sound (MacKenzie, 1969). In unprotected areas, starfish can reduce a commercially viable set of oysters to noncommercial levels in weeks. Under controlled laboratory conditions adult starfish have been observed to eat an average of five oysters each per 28-day period in water having an optimal temperature for feeding (20°C) (MacKenzie, 1969).

In New Haven Harbor, the abundance of starfish has steadily declined since 1974 when 17,000 individuals were collected (25% of the total catch) (Table 8-3 and 8-4). Numbers decreased to 7800 collected in 1975 (7% of the total catch) and 2700 in 1976 (4% of the total catch). The trend continued in 1977, when the total 9-month catch (630 individuals) decreased by 60% from that recorded during the same 9-month period in 1976 (2100 individuals). A consistent decline was observed at all stations in the harbor.

Long-term fluctuations in the abundance of starfish are well documented (Galtsoff, 1964). High yearly abundances are often followed by years of relatively low numbers. Such fluctuations are attributable to variations in survival of planktonic larvae as well as larval setting success (Galtsoff and Loosanoff, 1939). It is likely that the decline in abundance of starfish in New Haven Harbor here reported was a result of such natural fluctuations. This conclusion is further supported by the fact that monitoring data collected in New Haven Harbor since October 1977 revealed an upward trend in starfish abundance during 1978,

to levels similar to those observed during 1976. A second factor which may contribute to the observed decline in the abundance of starfish is "mopping" and the use of biocides such as lime (calcium oxide) by commercial oyster companies to protect oyster beds from starfish predation. "Mopping" consists of dragging large mops over oyster beds for approximately 10 minutes; starfish clinging to the mops are hauled from the water and destroyed. Lime is spread over the bed to keep starfish from feeding and to destroy them. Oyster beds in New Haven Harbor, as well as other parts of Long Island Sound, are periodically treated by both methods to keep the abundance of starfish, molluscs and oyster-fouling organisms to a minimum (MacKenzie, 1970 and 1977). Periodic treatment of oyster beds by "mopping", biocides or both would be expected to result in a decline in starfish abundance in the general vicinity of the treated area. Because of the relatively small size and semi-enclosed nature of New Haven Harbor, continued "mopping" and biocide protection of oyster beds could play a dominant role in the steady decline of the harbor population of *Asterias*.

During each year of the program, monthly variations in abundance of *Asterias* were considerable and no apparent trends were evident (Figure 8-4). In a review of over 40 years of data relating to abundance of *Asterias* in coastal waters between New Haven and Bridgeport, Loosanoff (personal communication, 1975) found no trends or patterns in starfish abundance (NAI, 1977). Similarly, no seasonal patterns of starfish abundance were evident in Stamford Harbor during the 1971-1973 Stamford Harbor Ecological Studies (NAI, 1974).

Despite the annual decline in abundance, patterns of distribution of *Asterias* as indicated by trawl data have been relatively consistent throughout the monitoring study. Highest abundances occurred in Morris Cove (Station 13) and in the main shipping channel in the vicinity of the Harbor Station discharge and middle harbor (Table 8-3). Since starfish are attracted to active oyster beds (Galtsoff, 1964) that are not sampled in this program, harborwide starfish distribution may be somewhat different than indicated by trawl data. Starfish are slightly

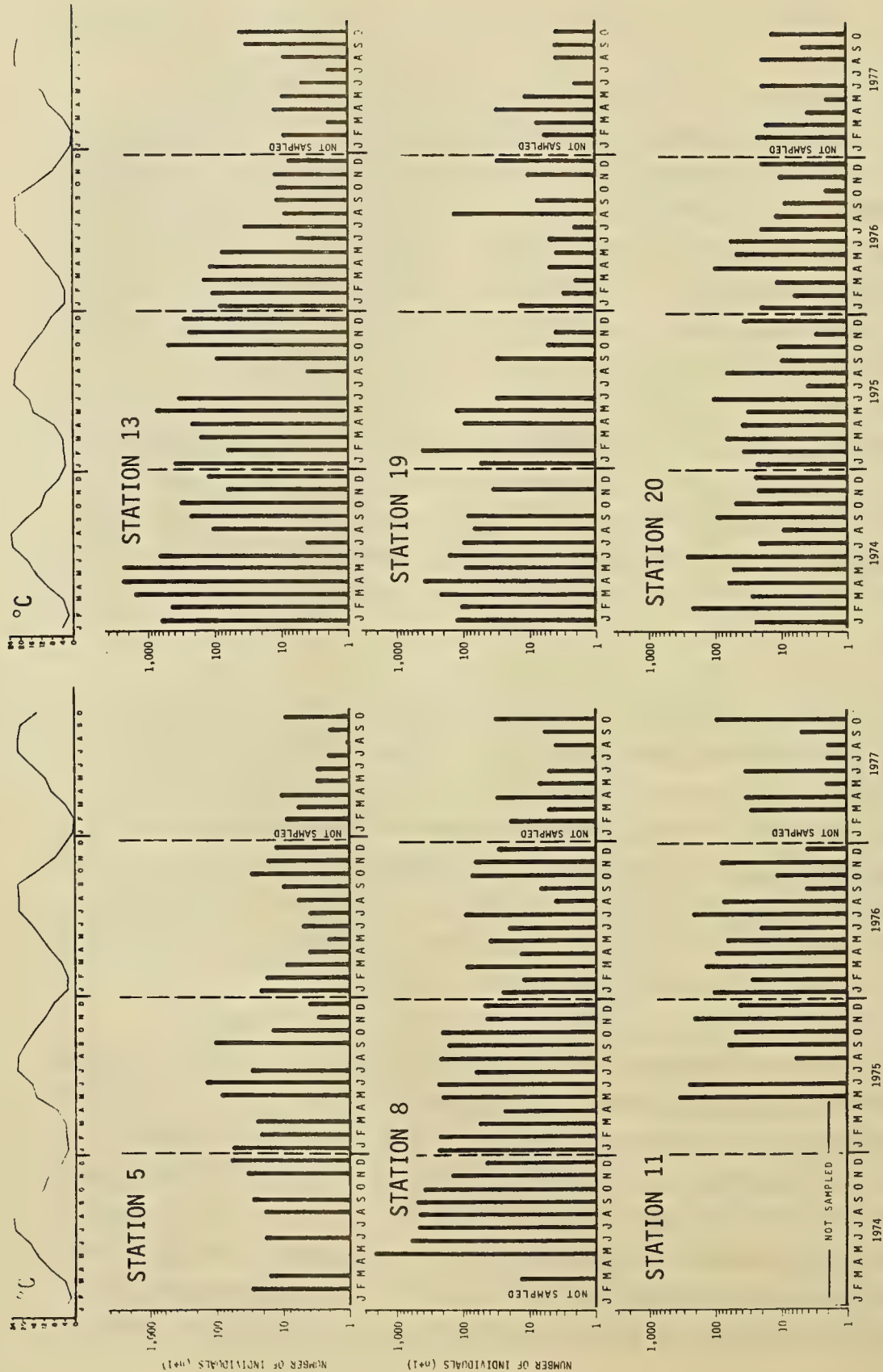


Figure 8-4. Monthly abundance of *Asterias forbesi* collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

stenohaline in that they prefer water of high salinity (Galtsoff, 1964). As such, they are somewhat restricted from the innermost harbor area, particularly during the spring. The same situation was observed at Stamford Harbor (NAI, 1974), where *Asterias* was rarely found at the innermost harbor station.

From July 1976 through October 1977 *Asterias* ranged in size from 25 mm to 132 mm and averaged 99 mm (NAI, 1978a and 1977). No seasonal or distributional trends in size of starfish were evident from the limited size data acquired during that sixteen-month period.

Cancer irroratus

The rock crab, *Cancer irroratus*, ranked third in overall abundance of epifauna from 1974 through 1977 (Table 8-4). It ranges from Labrador to South Carolina (Williams, 1965; Gosner, 1971) and has potential value as a commercial fisheries resource (Marchant and Holmser, 1975). Toward the southern extent of its range, *Cancer* is more common in deeper water. Water temperatures ranging from 14 to 21°C (Marchant and Holmser, 1975) and salinities of 20 to 32 ppt are optimal for adult *Cancer*. Although termed the rock crab, *Cancer irroratus* is most common on sandy bottoms (Jeffries, 1966; Saila and Pratt, 1973). It does, however, venture on to coarse gravel and mixed rocky bottoms (Musich and McEachran, 1972) as well as muddy bottoms (Scarratt and Lowe, 1972). Rock crabs feed actively upon polychaetes, mussels, gastropods, starfish and sea urchins, and most food appears to be taken alive (Scarret and Lowe, 1972). Rock crabs in turn are preyed on by large demersal fish and lobsters (Scarret and Lowe, 1972).

In New Haven Harbor, the annual abundance of *Cancer* varied over the course of the monitoring program with lowest abundances observed during 1975 and 1976 (approximately 700 individuals each year) and highest abundances during 1974 (2500 individuals) and 1977 (1400

individuals) (Table 8-3). Such yearly variations may be attributed to natural fluctuations in growth, mortality and recruitment as well as variations in catch success of the otter trawl. Similar fluctuations in the annual abundance of *Cancer* have been observed in other New England waters (Turner, 1954).

Populations of *Cancer* in the harbor showed a well-defined seasonal pattern of abundance (Figure 8-5). Although the pattern exhibited some variability from year to year and station to station, highest numbers were typically encountered during the winter, spring and fall. A substantial decline was coincident with periods of high water temperatures and low dissolved oxygen during July, August and September. Seasonal distribution of *Cancer* in New Haven Harbor, by year, is shown in Figure 8-6. *Cancer* was generally most abundant in the outer harbor during fall and winter with abundances increasing in the inner harbor during spring. During summer *Cancer* was collected in low abundances at all stations sampled. Abundances again increased in the outer harbor with the return of fall. This pattern occurred during each year with only minor exceptions.

Although extensive migratory behavior is not characteristic of *Cancer*, local inshore-offshore movements have been documented for populations located near their southern geographic limit (Saila and Pratt, 1973) where *Cancer* is abundant in shallow waters during the colder months only; during summer it migrates to deeper waters. In New Haven Harbor migration generally begins around April or May, and immigration from the Sound to the harbor occurs in October. This is similar to observations by Winget *et al.* (1974) for *Cancer irroratus* in Delaware Bay, where crabs began migration from the bay in April and returned in November. Similar patterns of abundance were observed at Stamford Harbor during the 1971-1973 Stamford Harbor Ecological Studies (NAI, 1974) and at Port Jefferson during the 1976 pot survey of commercially important invertebrate species (EEHI, 1977).

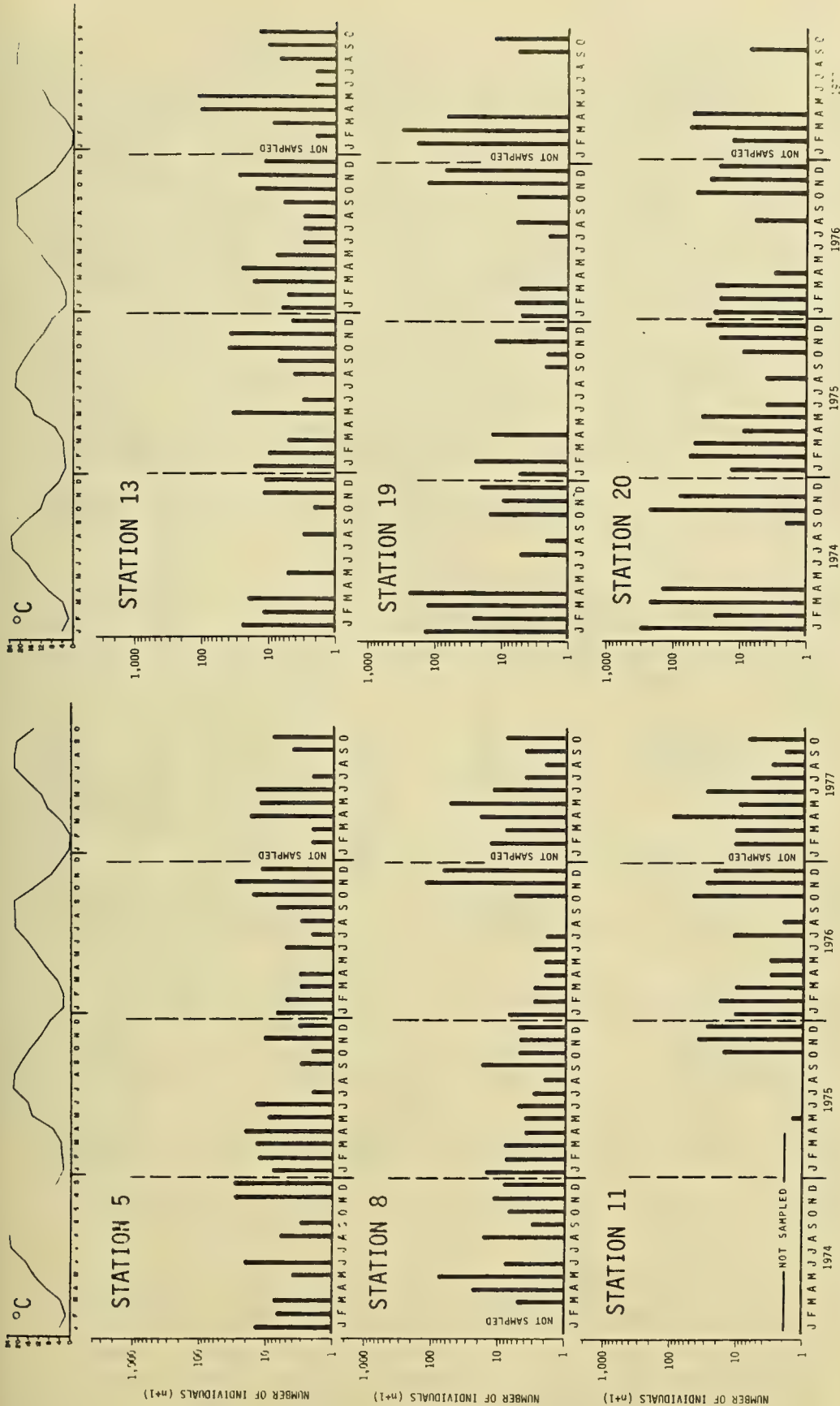


Figure 8-5. Monthly abundance of *Cancer irroratus* collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

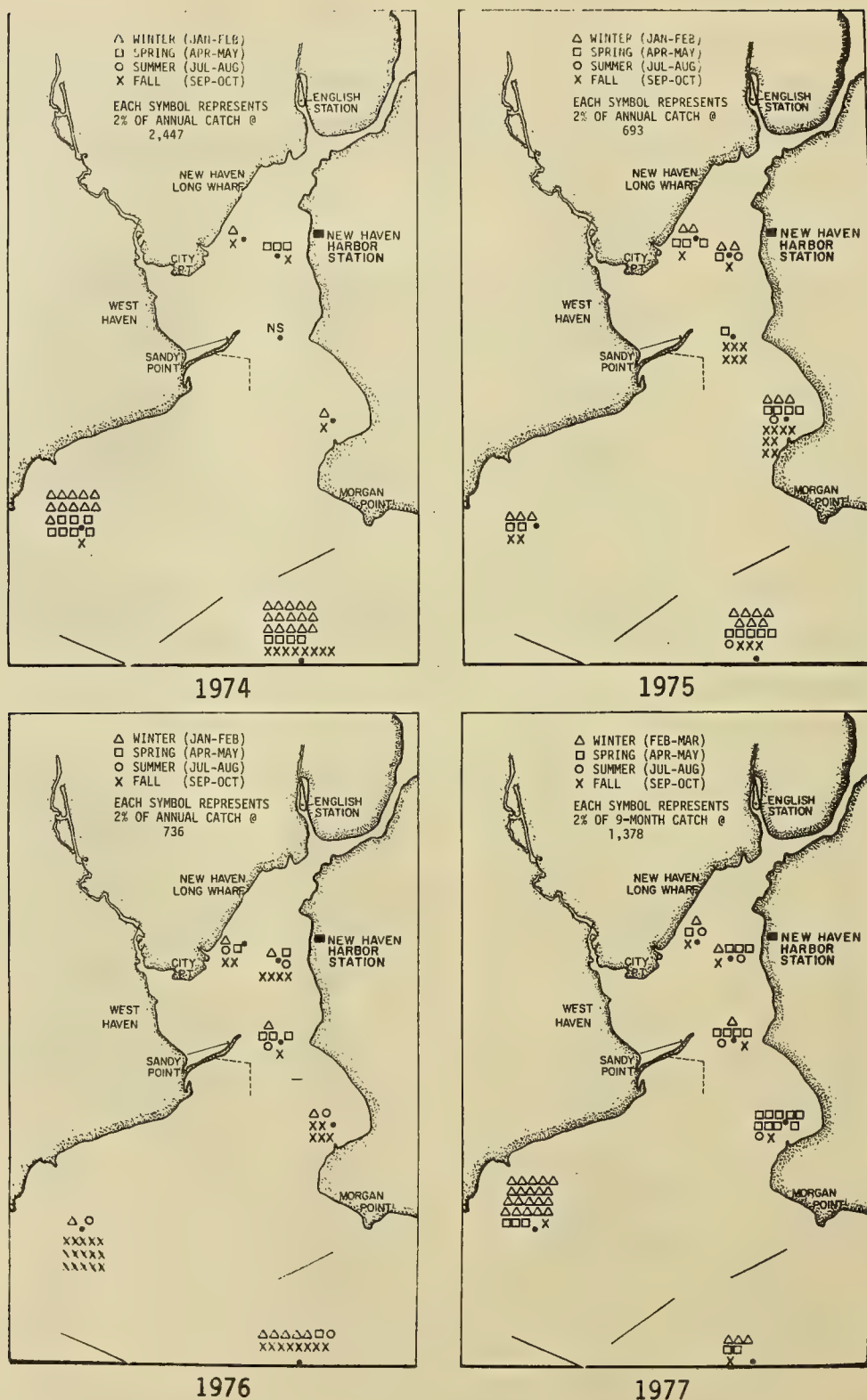


Figure 8-6. Distribution of *Cancer irroratus* by season in New Haven Harbor from 1974 through 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

In a study of the rock crab, *Cancer irroratus*, and the spider crab, *Libinia emarginata*, in Delaware Bay, Winget *et al.* (1974) observed that the occurrence of *C. irroratus* was generally opposite that of *L. emarginata*. Whereas *Cancer* was most abundant from November through April, *Libinia* was generally most abundant from April through late October and early November. In New Haven Harbor *Libinia* has been collected in relatively low numbers; however, as demonstrated by Winget *et al.*, it has occurred most abundantly from June through October when *Cancer* abundance in the harbor was low. No apparent interrelationship of the species exists that would account for the relationship between the migratory patterns of these two species; however, it is reasonable to assume that competition for available food and habitat resources is diminished by this general migratory scheme. Differences in the migratory pattern of these two species could also be related to differences in their temperature tolerances. *Cancer* is a boreal species, and as such is more tolerant of cold temperatures and less tolerant of high summer temperatures. *Libinia* on the other hand, is more of a warm-water species, and therefore, is more tolerant of high summer temperatures and less tolerant of low winter temperatures.

Although it is not certain when *Cancer* spawns in New Haven Harbor, evidence indicates that spawning (egg extrusion and fertilization) takes place during late fall or winter, brooding continues into spring and the developing eggs hatch into planktonic larvae in late spring-early summer (NAI, 1978a, 1977 and 1976a). Scarrett and Lowe (1972) reported peak abundances of *Cancer* larvae in the Northumberland Strait, Gulf of St. Lawrence, during late summer. Krouse (1972) indicated that *C. irroratus* spawn during late fall-early winter along the Maine coast and that eggs hatch during the spring. During 1977 the abundance of *Cancer* larvae in New Haven Harbor was relatively low, but peak abundances occurred during June (NAI, 1978a). Prior to 1977, *Cancer* larvae were not specifically identified, but decapod larvae, which probably included *Cancer*, were present in the plankton only from May through August. Since *Cancer* begins its migration to deeper waters during April and May, it can be expected that a substantial amount of larval development occurs outside the harbor. This is important in two respects. The

first is that water temperature in the harbor during June averages approximately 16 to 19°C and increases to greater than 20°C during July and August. Optimal growth of *Cancer irroratus* larvae occurs at 15°C, and at temperatures above 20°C the metabolic rate is reduced (Saila and Pratt, 1973). Thus, larvae hatched in deeper waters during late spring and summer would not be subjected to deleteriously high water temperatures. Secondly, if, as is indicated, a substantial amount of larval development occurs in deeper waters, larval entrainment by the Harbor Station would be minimized.

Most rock crabs collected in the harbor were relatively small, ranging in size (greatest carapace width) from 2 to 80 mm, while most were from 45 to 65 mm (adult carapace width averages approximately 95mm [Williams, 1965] and reaches 140 mm [Gosner, 1931]). No temporal or spatial trends in size of *Cancer* were evident. Low abundance of crabs and a lack of size data during summer may prevent detection of possible seasonal size patterns.

Ovalipes ocellatus

Ovalipes ocellatus, the lady or calico crab, ranges from Prince Edward Island, Canada, to Charleston, South Carolina and is common on a variety of bottoms, particularly sand (Williams, 1965). Like most portunid crabs, *Ovalipes* is quick, highly aggressive, and pugnacious (Gosner, 1971). The annual abundance of *Ovalipes* has shown considerable yearly variation (Table 8-3). Lowest abundances were collected during 1974 (60 individuals) and 1976 (200 individuals), while highest abundances were collected during 1975 (1400 individuals) and 1977 (3220 individuals). A comparable trend in annual abundance is apparent in the impingement data for the New Haven Harbor Station (Table 8-5, page 8-44). Generally, *Ovalipes* has been most abundant in the inner harbor and Morris Cove. Moderate numbers occurred in the middle harbor (Station 11) and relatively few in the outer harbor (Stations 19 and 20) (Table 8-3). During 1975 and 1977 when annual abundances were high, Morris Cove (Station 13) accounted for 80% of the total catch of *Ovalipes*.

Ovalipes exhibited a well-defined seasonal pattern of abundance in New Haven Harbor (Figure 8-7), with the largest numbers being consistently collected during the late summer and early fall. Based on abundance data, *Ovalipes* enters the harbor during summer, reaches peak abundances during early fall and leaves the harbor before onset of winter. A similar peak in abundance was observed in Stamford Harbor during 1972 (NAI, 1974) and impingement data from Bridgeport (1977), Millstone (1977) and New Haven Harbor (1975-1977) also reveal fall peaks. In New Haven Harbor a small spring peak was also evident in the impingement data during 1976 and 1977 (Table 8-5); this was not evident in the trawl data.

It is not certain why *Ovalipes* migrates to the harbor during summer and fall or even where it may be migrating from. However, as with *Libinia*, one advantage of the summer-fall migration is that competition for food and habitat resources with *Cancer* may be minimized. Since preferred habitat and food resources are similar for these two species, this type of migratory scheme allows *Ovalipes* to inhabit inshore waters when the abundance of *Cancer* is low, and offshore waters when inshore *Cancer* abundances are high, thus decreasing interspecific interactions. Little interaction is expected between *Ovalipes* and *Libinia* (also a summer-fall migrant) since these two species generally utilize different areas of the harbor, *Ovalipes* being collected most abundantly in the inner harbor and Morris Cove, and *Libinia* in the outer harbor at Stations 19 and 20.

Homarus americanus

The lobster, *Homarus americanus*, is the most commercially and recreationally valuable crustacean along the coast of northeastern United States (Saila and Pratt, 1973). It ranges from Labrador to North Carolina and is common in Long Island Sound. In southern New England waters, *Homarus* is abundant from the subtidal zone to the edge of the continental shelf. South of Long Island, however, it is restricted to deeper waters due to warm temperatures and a lack of suitable substrate

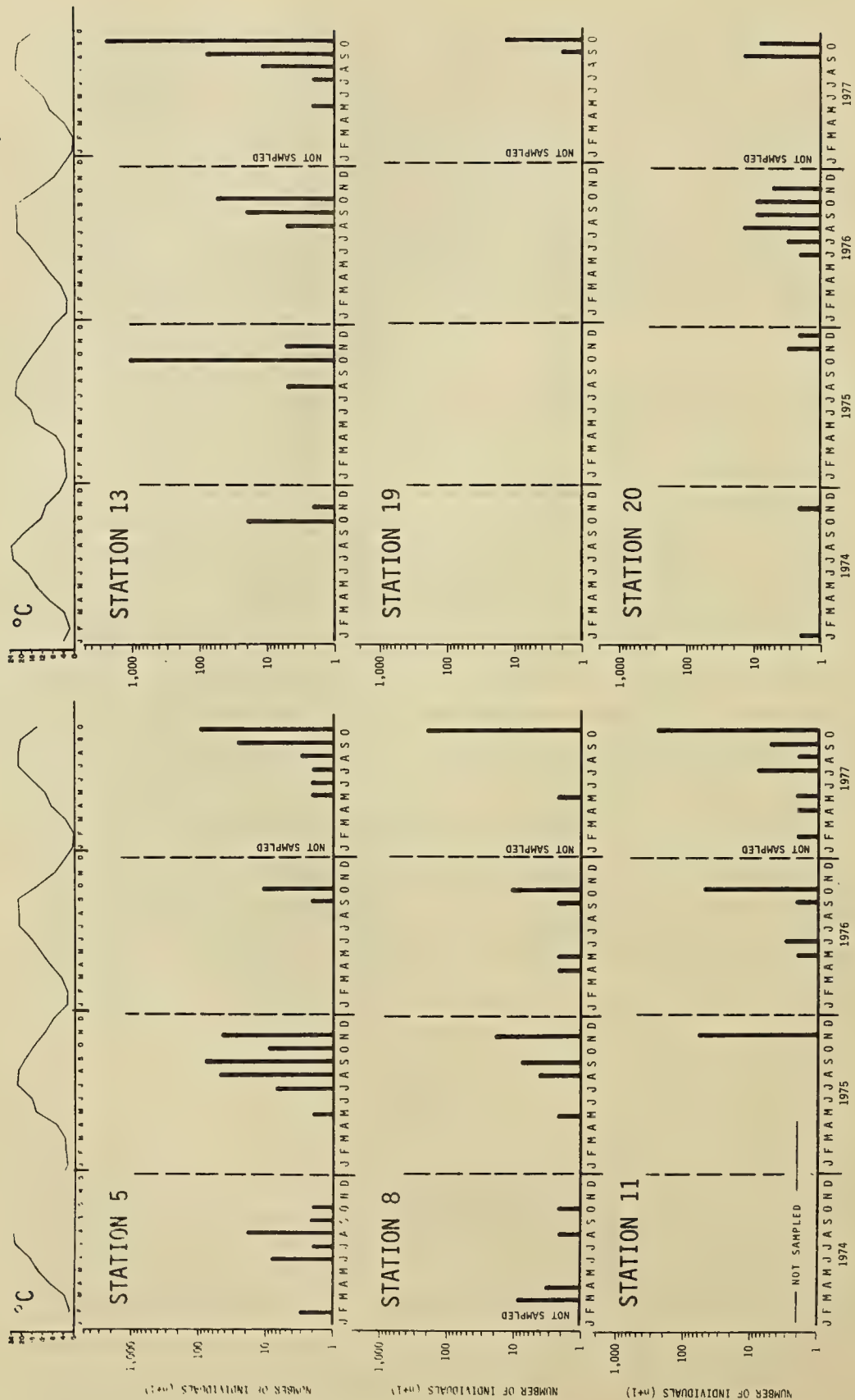


Figure 8-7. Monthly abundance of *Ovalipes ocellatus* collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

(Saila and Pratt, 1973). Lobsters are common to both rocky and muddy areas (Saila and Pratt, 1973; Berril and Stewart, 1972). Both these completely different types of habitat provide the lobster with shelter, either by the presence of crevices or ledges to hide in, or in the case of muddy areas, the opportunity to excavate burrows.

In New Haven Harbor, lobsters were generally collected in low abundance, accounting for 1% by number of the total catch during every year of the program (Table 8-4). Lobsters are nocturnal, spending much time in their shelters during the day and being most active during the night. Hence, daytime trawls only sample a small percentage of the total population. Lobsters were collected throughout New Haven Harbor: highest abundances occurred in the shipping channel in the vicinity of the Harbor Station discharge (Station 8) and in the middle harbor area (Station 11), with moderate abundances in Morris Cove (Station 13) (Table 8-3). Lobsters were typically collected in lowest abundances in the shoal area between Long Wharf and the City Point sewer outfall (Station 5), and the outer harbor area (Stations 19 and 20).

Seasonal patterns of abundance were apparent for lobster populations in New Haven Harbor particularly at Stations 8 and 11 where abundances were highest (Figure 8-8). Abundances increased during the late spring-early summer (May and June), declined in July and August, and often increased again in the fall (September-November). Spring and fall peaks were coincident with moderate water temperatures (8-17°C) and low numbers with extreme temperatures (0-3°C and 19-24°C). This correlates well with known patterns in lobster activity. McLeese and Wilder (1958) have shown that lobster activity increases between 2 and 25°C with a plateau between 10 and 20°C. Temperatures above 25°C resulted in substantial decreases in activity and eventually led to complete inactivity.

Peak abundances in the trawl samples during spring and fall may reflect increased lobster activity during these periods of optimal water temperature. Low abundance during winter and possibly summer may

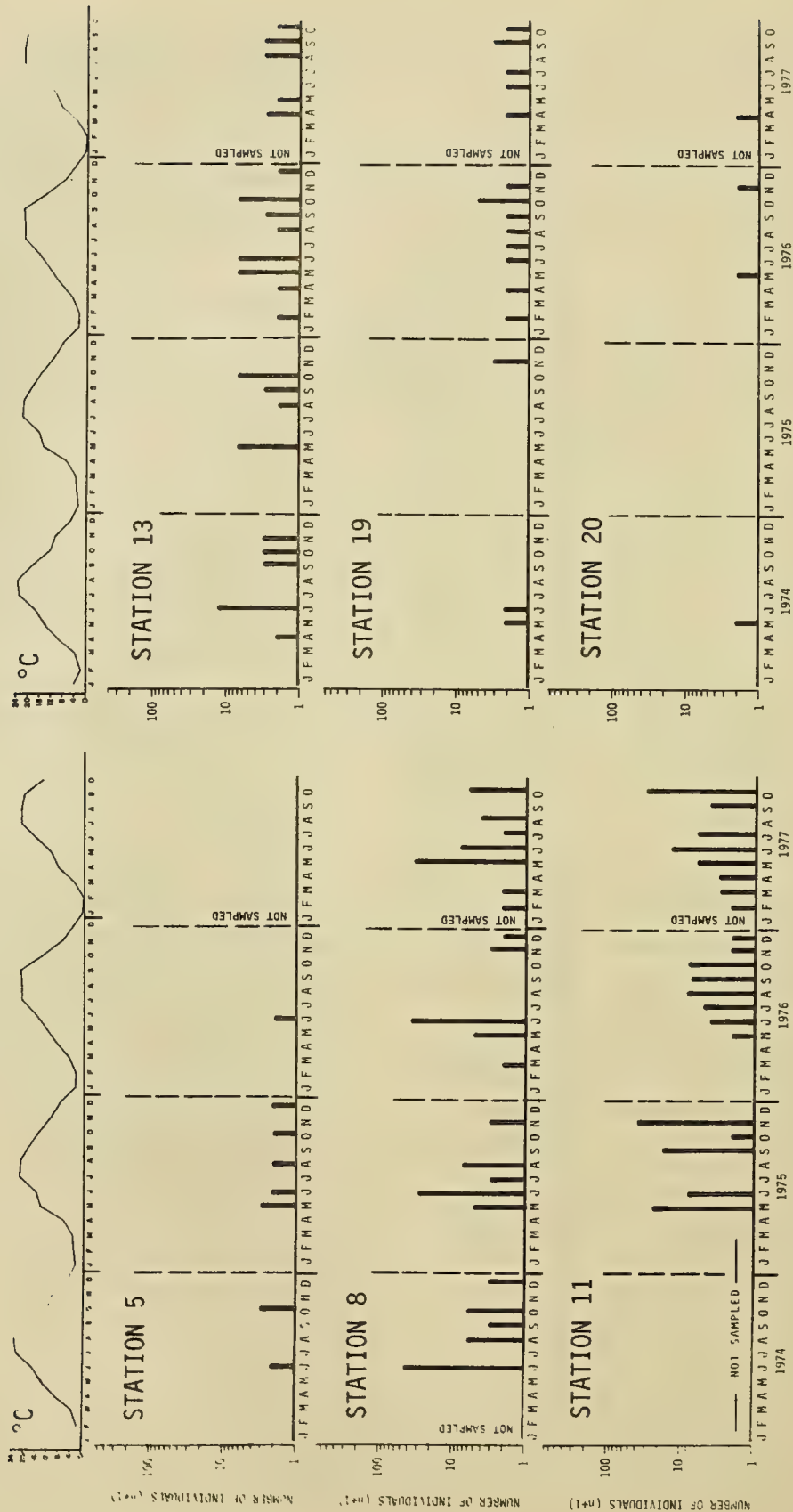


Figure 8-8. Monthly abundance of *Homarus americanus* collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

be due to a decline in lobster activity as a result of extreme water temperatures and therefore fewer individuals collected in trawls. Similar patterns of abundance have been observed at other Long Island Sound sites. Thus at Port Jefferson (EEHI, 1977), lobster abundance during 1976 increased from winter to spring and decreased during the summer; however, no fall peaks in lobster abundance were observed. In Stamford Harbor (NAI, 1974) peak abundances of lobster occurred during fall, 1971, 1972, and 1973, while a spring peak was also observed during 1971. At Millstone Point (NUSCO, 1976) lobsters were impinged on cooling-water intake screens of the Millstone Nuclear Power Station in highest abundances during May and June, 1976, and in lesser abundances in July; numbers were low during winter, late summer and fall. Whether or not lobsters in New Haven Harbor migrate during periods of increased activity is not certain. However, although inshore lobster populations are generally non-migratory, seasonal movements related to changes in depth and substrate do occur (Saila and Pratt, 1973). For example, immigration and emigration of lobsters in Fisher's Island Sound has been described by Stewart (1972); lobster populations were observed to emigrate from the Sound during spring and early summer, and immigrate to the Sound during fall, remaining until the following spring. This correlates with abundance patterns observed in New Haven Harbor.

Squilla empusa

The stomatopod shrimp, *Squilla empusa*, ranges from New England to South America and is found in shallow waters of the subtidal zone to depths of 154 m (Gosner, 1971). The mantis shrimp is a raptorial carnivore that feeds primarily on small fish and decapod shrimp (Caldwell and Dingle, 1976). A burrower, *Squilla* lives in irregular shaped holes and trenches in the bottom. Examination of mantis shrimp burrows has revealed that two distinct types of burrows are constructed and inhabited on a seasonal basis (McCluskey, personal communication). During the summer *Squilla* inhabits relatively shallow U-shaped burrows often with two openings. During winter in northern waters *Squilla* abandons its summer burrow and inhabits a deep vertical burrow (up to 4.4 m) con-

ceivably excavated in an attempt to avoid intolerably low water temperatures ($<5^{\circ}\text{C}$) (McCluskey, 1977). Laboratory observations have shown that individuals without burrows die when exposed to water temperatures of 5°C ; while individuals within burrows survive temperatures to 0°C (McCluskey, 1977). Except during winter, when *Squilla* is inactive and deep in its burrow, it spends much time at the entrance to its burrow in wait of prey (Caldwell and Dingle, 1976).

In New Haven Harbor, the abundance of *Squilla* as determined by trawl sampling is highly seasonal (Figure 8-9). Peak abundances were observed during September, October and November coincident with declining seasonal temperature maxima. During the remainder of the year abundances were extremely low. It is not clear why the *Squilla* catches peak in abundance during the fall, but it may be related to mating (occurring out of the burrow) or possibly its change from summer to winter burrow. This is supported by the fact that increased epibenthic activity of *Squilla* during October and November is also reflected in the 1976 impingement data from Port Jefferson and Glenwood, as well as the New Haven Harbor Station impingement data for August 1975 through October 1977. As in otter trawl samples, *Squilla* was found impinged in highest abundances during October and November, and in low abundances during the remainder of the year.

On an annual basis, *Squilla* was typically collected in low numbers. *Squilla* ranked 8th in overall abundance from 1974 through 1977 comprising less than 0.1 percent to 0.6 percent of the total catch (Table 8-4). *Squilla* was found in highest abundances at Stations 8 and 11 (Table 8-3). Because of its burrowing behavior, abundance is to a large degree related to suitable habitat. *Squilla* is typically found on silty/clay or muddy bottoms where burrows can easily be excavated (Gosner, 1971). Based on benthic grab samples taken in the main channel in the vicinity of the Harbor Station discharge and middle harbor region (NAI, 1978a), as well as analysis of marine sediments adjacent to the New Haven Harbor Station (NAI, 1972), black to gray marine mud is predominant in this area. This type of sediment permits the excavation of deep burrows essential for winter survival of *Squilla*.

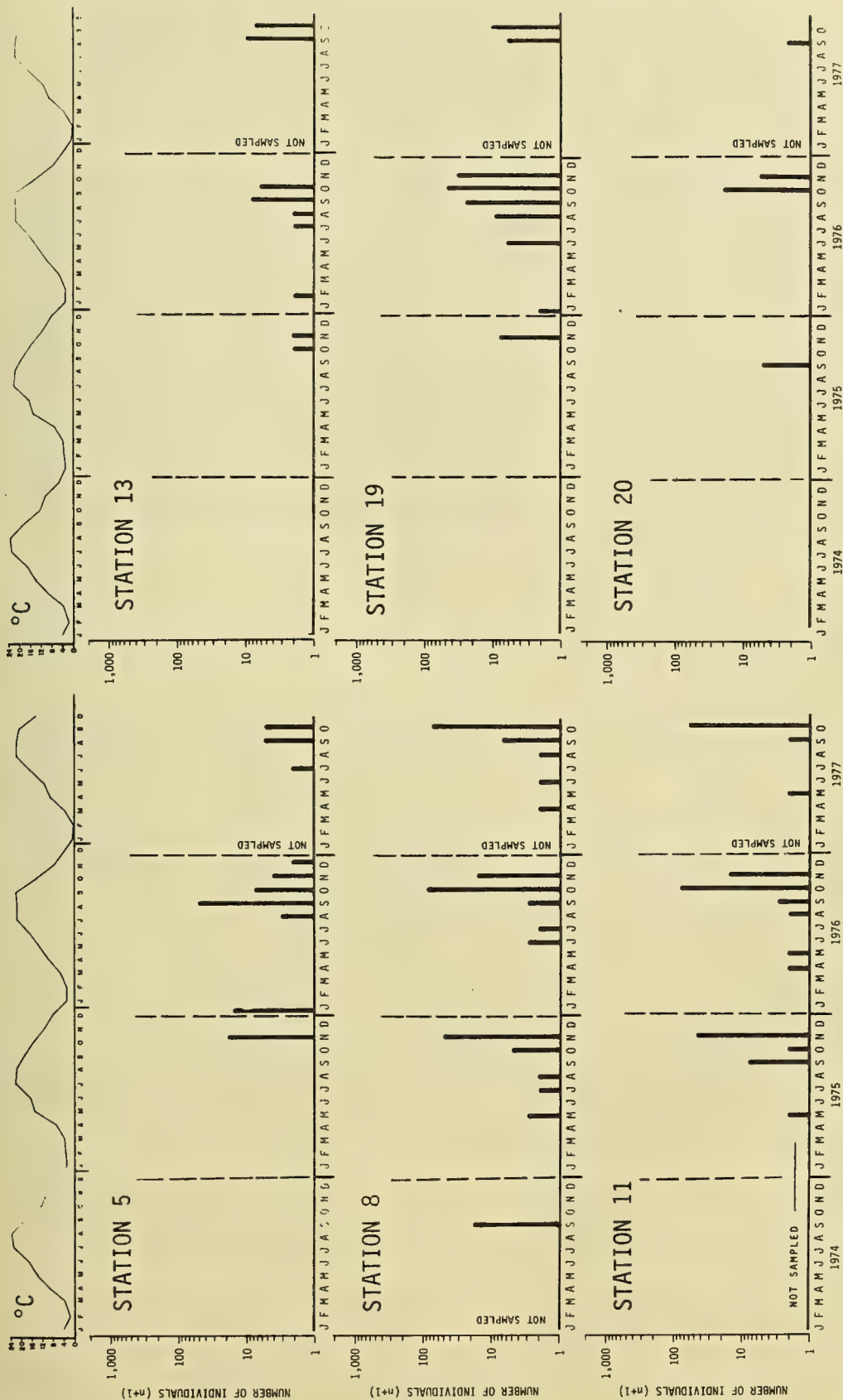


Figure 8-9. Monthly abundance of *Squilla empusa* collected in 10-minute epibenthic trawls from Stations 5, 8, 11, 13, 19 and 20, January 1974 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Catch-data collected during the survey indicate that *Squilla* occurs in relatively low abundances; however, because of the burrowing nature of mantis shrimp, otter trawls cannot be expected to provide a reliable estimate of *Squilla* abundance. Benthic grabs are also ineffective since mantis shrimp can move deep into their burrows away from the area sampled by the grab. Gosner (1971) gives account of a lysiosquillid which went undetected on the south shore of Cape Cod, an area of frequent ecological investigations, until 1958. Caldwell and Dingle (1976) indicate that although *Squilla* are numerous enough in some waters to be a major predator, they are not collected in high abundances because of their burrowing behavior. It is likely that *Squilla* are much more abundant in New Haven Harbor than catch data indicate and that they may contribute more significantly to ecosystem dynamics in the harbor than has heretofore been assumed.

ANALYSIS OF IMPACT

Epibenthic organisms may be directly affected by power plants in three major ways: 1) by contact with elevated temperatures associated with the thermal discharge plume, as well as sudden cooling of waters influenced by the plume whenever the plant shuts down; 2) by entrainment of eggs and larvae in the water passing through the power plant's cooling system; and 3) by impingement of organisms on the cooling-system intake screens. In this section, the possible effects on the epibenthic community of these three modes of impact are discussed and related to the situation observed in New Haven Harbor, and an analysis of impact of the Harbor Station on the epibenthos is presented based on data collected prior to and during operation of the New Haven Harbor Station.

The effects on estuarine organisms of elevated temperatures from power plant thermal effluents are well documented (Talmage and Coutant, 1978). A discussion and literature review of the tolerances and responses of marine invertebrates to natural and artificial temperature regimes has been presented by Kinne (1970). The effects of elevated temperature on most organisms appears to be greatest during the reproduc-

tive, embryonic, and larval developmental stages (Kinne, 1970). Spawning in many marine organisms is stimulated by the attainment of a certain minimal water temperature (Davis, 1972; Mitchell, 1974; Wilson and Seed, 1974; Crawford and Homsher, 1975; Kinne, 1970). Above-normal seasonal temperatures can result in spawning at inappropriate times with a resulting decrease in larval survival success. Embryonic development is inhibited above a certain species-specific critical temperature (Davis, 1972; Kinne, 1970; Talmage and Coutant, 1978). This inhibition can lead to prolonged planktonic existence, and consequently a longer exposure of the organism to intensive predation with a resulting decrease in the probability of survival. In New Haven Harbor, the influence of elevated water temperatures on reproduction and embryonic and larval development is not considered of major significance to the viability of the adult populations, since the extent of the thermal impact area is limited ($\Delta t \geq 1^\circ\text{F}$ detectable over a maximum of 42% of the inner harbor surface, Section 3.0) and because the harbor does not appear to be a major spawning ground for most of the epibenthic invertebrates present. This second position is supported by the relatively low densities of larval epibenthic invertebrates collected annually in plankton tows (Section 4.0). The decapod crustaceans -- including *C. septemspinosus*, *C. irroratus*, *O. ocellatus*, and *H. americanus* -- comprise the most numerous group of invertebrates collected in bottom trawls; yet comparatively low larval densities of this group have been observed in the plankton (yearly average of 4.5 to 23.3 larvae/m³/month) (Section 4.0). This and evidence indicating that some invertebrates such as *C. septemspinosus* and *C. irroratus* migrate from the harbor prior to the egg-hatching period, suggest that Long Island Sound supplies the major source of juveniles for most epibenthic invertebrate populations in the harbor. Recruitment to the adult population of larvae from the harbor is believed to be small in comparison to the contribution to the harbor of juvenile animals from Long Island Sound.

Artificially elevated temperatures associated with a power plant discharge can also influence adult distribution with a resulting change in community structure (Kinne, 1970; Logan and Maurer, 1975;

Talmage and Coutant, 1978). Because of the mobility of many epibenthic invertebrates, avoidance of or attraction to the thermal plume can readily occur and result in a change in species richness and individual species abundance. Logan and Maurer (1975) observed an area subjected to thermal effluent discharge in which species number and individual species abundances decreased.

Increased water temperatures can result in changes in the occurrence of species located near their thermogeographic limit. In New Haven Harbor, *Homarus americanus*, for example, is abundant to the south of Long Island Sound in offshore waters only (Saila and Pratt, 1973); it avoids inshore waters because of high temperatures as well as a lack of suitable substrate. In terms of inshore populations, Long Island Sound can be considered a thermogeographic limit for the lobster (Saila and Pratt, 1973). Harbor-water temperatures increased above normal could exclude lobsters, particularly from the area of the thermal discharge. On the other hand, species such as *Panaeus aztecus*, *Libinia dubia*, *Callinectes sapidus*, *Panopeus herbstii*, *Eupleura caudata* and *Haminoea solitaria* are epibenthic species in New Haven Harbor living at the northern extremes of their geographic range. Increased temperatures could allow a greater abundance of these species to inhabit or frequent the harbor and this in turn would have an effect on the natural community structure through competition for available resources.

Sudden decreases in water temperature can be more detrimental to organisms inhabiting an area than long-term temperature elevations (Kinne, 1970). Acclimation of marine organisms to artificially elevated water temperature during winter can result in the organisms' inability to return to ambient water temperatures in the event heating by the power plant stops (Pennsylvania Fish Commission, 1971; Robinson, 1970; cited in Water Quality Criteria 1972, EPA-R3-73-033). In such cases where the thermal discharge suddenly stops, cold-shock may occur.

In New Haven Harbor, direct impacts of the thermal discharge on the distribution and occurrence of epibenthic invertebrates present

little problem, since the thermal plume generally does not influence bottom waters to a measurable extent. The "Analysis of Impacts" portion of the Hydrographic section (Section 3.0) indicates that the thermal plume is essentially a near-surface feature. Even in the area of the discharge, bottom waters are usually close to ambient. The maximum observed temperature increase for bottom waters in the area of the discharge was approximately 2°F and bottom-temperature elevations of this magnitude are uncommon. For this reason impacts on the epibenthos in New Haven Harbor as a result of artificially elevated water temperatures and sudden cooling of the water when the plant goes off-line can be expected to be minimal.

Entrainment of eggs and larvae of epifaunal organisms has the potential for serious impact on the epibenthic community. This is particularly true for resident species that reproduce within the limits of the harbor. For these species, chronic destruction of a portion of the egg and larval stages could eventually result in observable decreases in the population. We do not, however, consider entrainment of eggs and larvae of the epibenthic invertebrates in New Haven Harbor to present a serious threat to the epibenthic community for two reasons. First, based on annual meroplankton abundances in New Haven Harbor (Section 4.0), and to some extent the behavioral tendencies of the epibenthic organisms, it appears likely that Long Island Sound supplies the major sources of eggs and larvae and that, as indicated previously, no major spawning occurs in the harbor. Secondly, assuming 100% mortality of entrained eggs and larvae, because of the comparatively small cooling water flow of the New Haven Harbor plant (0.7% of the average tidal flow rate) and the large exchange of harbor water with Long Island Sound (assumption based on a tidal prism of 43% of the harbor volume at MSL coupled with a general LIS net flow pattern past the harbor mouth), it is reasonable to assume that only a minute percentage of the eggs and larvae present in the harbor pass through the power-plant cooling system. This amount is wholly insignificant in comparison to the quantity of eggs and larvae that move in and out of the harbor with the tides.

Mortality due to impingement on cooling-water intake screens can also have serious consequences on marine organisms (Uziel, 1978). Impinged organisms may die directly as a result of mechanical abrasion or simply by being removed from the water when the screens are cleaned. Animals that are returned to the water may die indirectly as a result of high stress conditions which lead to decreased resistance to disease and predation, or an inability to compete for food (Hanson *et al.*, 1977). Impingement of epibenthic invertebrates on the cooling-water intake screens of the New Haven Harbor Station is discussed in some detail on page 8-43; it does not appear to be detrimental to the populations as a whole.

Given the limited impacts of Station operations as surmised and the general structure of the epibenthic monitoring program, it is not possible -- with any degree of confidence -- to evaluate specifically the individual effects of the three major modes of impacts of the Harbor Station on the epibenthos in New Haven Harbor, i.e., effects of contact with elevated temperatures or exposure to sudden decreases in temperature, entrainment of eggs and larvae in the power plant's cooling system, and impingement of adults on the cooling-system intake screens. The program was designed to allow evaluation of the total impact of the Harbor Station on the epibenthos -- that is, the cumulative effects of all potential modes of impact. This has been accomplished by comparing annual trends in species composition, abundance and distribution prior to and during operation of the New Haven Harbor Station.

In terms of the overall composition of the epibenthic fauna in New Haven Harbor, only minor changes have been observed since the initiation of the New Haven Harbor Station Ecological Monitoring Studies. These changes are primarily related to improvements in field identification with a resulting increase in levels of identification; secondarily they are related to the incidental occurrence of species not commonly collected in otter trawls. The total number of epibenthic species collected annually was similar for each year of the study and ranged from 24 to 28 (Table 8-1). Of the 44 epibenthic species encountered

during the seven-year program, 14 were encountered every year of the study (1971-1977). An additional six were encountered during all of the last five years (1973-1977). Thus, of the 24 to 28 invertebrate taxa collected annually beginning in 1973, 20 taxa or 70 to 80% of those collected each year were common to all years. The remaining 20 to 30%, 4 to 8 species, that were not collected consistently were made up of species which: 1) are not commonly collected in otter trawls (*Crepidula convexa*, *Haminoea solitaria* and *Retusa obtusa*), 2) generally occur in low abundances in the areas sampled (*Eupleura caudata*, *Palaemonetes vulgaris*; and 3) are near their northern geographic limit and occur occasionally in the harbor (*Libinia dubia*, *Penaeus aztecus*).

Variations in annual abundance of the 12 most commonly collected invertebrate species during preoperational and operational years generally fall into four main categories (Table 8-3): 1) small with no substantial difference between years -- i.e., *Pagurus longicarpus*, *Homarus americanus*, and *Neopanopi sayi*; 2) fluctuating, with periods of high and low abundances observed during both preoperational and operational years -- i.e., *Ovalipes ocellatus*, *Cancer irroratus*, *Ilyanassa obsoletus*, *Nassarius trivittatus*, and *Crangon septemspinosa*; 3) trends of increasing abundance -- i.e., *Squilla empusa* and *Pagurus pollicaris*, and 4) trends of decreasing abundance -- i.e., *Asterias forbesi* and *Libinia emarginata*. Species included in the first two categories pose no particular concern since their abundances appeared stable over the period of this monitoring study. Abundance trends of species included in the last two categories warrant further consideration and explanation since long-term changes could conceivably be indicative of Harbor Station impact.

The hermit crab, *Pagurus pollicaris*, which belongs to the third category, is typically collected most abundantly in the outer harbor (Stations 19 and 20). Abundance in sampling hauls has increased from a yearly total of 9 in 1974 to 185 in 1977. Because of its restricted distribution to the outer harbor, however, it is doubtful that the Harbor Station discharge has any relationship to the increasing abun-

dance of this species. More likely, increasing abundances of *P. pollicaris* in the outer harbor are a result of natural variations in Long Island Sound populations. This is further substantiated by a lack of evidence indicating any elevation in bottom water temperatures in the outer harbor attributable to Harbor Station operation (Section 3.0). Unfortunately, however, there are no Long Island Sound studies which provide data on *P. pollicaris* abundances.

Squilla empusa, also in the third category, has been collected most abundantly in the vicinity of the Harbor Station discharge. Annual abundance of this species as indicated by sampling increased from 1974 through 1976 and decreased slightly during 1977 (Table 8-3). Because of their burrowing nature, however, mantis shrimp were not effectively sampled by otter trawl and it is therefore difficult to make any accurate conclusions concerning variations in annual abundances. Also, because this species has been collected abundantly only during one or two months of the year, it may be that during each year the trawl samples were taken during slightly different phases of the fall peak thus resulting in varying catch sizes from year to year.

The spider crab, *Libinia emarginata*, showed a general decrease in abundance from 1974 through 1977 (Table 8-3). This decrease was not considerable and probably reflected natural variations in catch success of the otter trawl. On a station-to-station basis, variations in annual abundance between preoperational and operational years were not substantial except at Station 20. At this station, high abundances (265 individuals) were observed during 1974; there were only 9 individuals observed in 1977. The high annual abundance figure for 1974 was primarily the result of a single large catch (265 individuals) of *Libinia* at Station 20 during June.

The starfish, *Asterias forbesi*, was the only species which showed any major changes in annual abundance. As indicated earlier, the abundance of *Asterias* decreased consistently from a high of 17,000 in 1974 to a low of 600 during the 9-month survey of 1977. Although it is

difficult to draw any definite conclusions as to the downward trend in starfish abundance in New Haven Harbor, it is doubtful that the observed decrease was in any way related to operation of the Harbor Station electric generating facility. The decline in starfish abundance first became apparent in March 1975, prior to the time that the Harbor Station went on-line (NAI, 1976a). Also, it is well documented (Galtsoff, 1964) that long-term fluctuations in starfish abundance occur: high yearly abundances are often followed by years of relative scarcity. Treatment of oyster beds in the harbor by mopping and with biocides also affects starfish abundance. Finally, the decline in starfish abundance was apparent at all stations sampled, including stations with low impact likelihood (Stations 13, 19 and 20), and no substantial changes in distribution were evident.

Rank of abundance by station, annually for the 12 most common epibenthic invertebrates, is presented along with annual species abundance by station in Table 8-3. Judging from annual abundance and station rank by year for each of the 12 selected species, it is evident that only minor variations in species distribution occurred between preoperational and operational years. These variations are probably primarily attributable to the mobility of epibenthic invertebrates as well as natural fluctuations in abundance and vicissitudes in catch success.

Variations in rank of abundance for all twelve species were notably small in the area of the thermal discharge (Station 8). In no case did species abundance and/or station rank indicate major changes in distribution. This is particularly important since Station 8 would be expected to have the greatest potential for manifesting direct effects of the discharge.

Several species of epibenthic invertebrates have been impinged on the traveling screens of the cooling-water intake system. *Cancer irroratus*, *Ovalipes ocellatus* and *Squilla empusa* were impinged in highest abundances (Table 8-5). Impingement of *Cancer* was high only during October and November 1975 (average of 200 per 24 hours). Since that

TABLE 8-5.

MEAN NUMBER OF EPIBENTHIC INVERTEBRATES IMPINGED PER 24 HOURS, MONTHLY, ON TRAVELING SCREENS OF THE NEW HAVEN HARBOR STATION COOLING WATER INTAKE SYSTEM. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

1975						
	A	S	O	N	D	
Cancer spp.	1.0		200E	200E	54.5E	
<i>Ovalipes</i> spp.	10.7	250E	300E	200E	57.5E	
<i>Squilla empusa</i>				275E	114.0E	
<i>Callinectes sapidus</i>						
<i>Carcinus maenas</i>						
<i>Homarus americanus</i>						
<i>Libinia dubia</i>						
TOTAL	12.6	250E	500E	675E	226.0E	

1976										
	J	F	M	A	M	J	J	S	O	D
Cancer spp.	0.3				2.5	6.0	2.3			
<i>Ovalipes</i> spp.	0.3	0.8	0.2	5.5	64.5	5.3	3.0	0.3		0.6
<i>Squilla empusa</i>					1.3	1.3	1.0			
<i>Callinectes sapidus</i>					2.8	1.3	1.3			
<i>Carcinus maenas</i>					0.3	1.0	0.2			4.6
<i>Homarus americanus</i>							0.4			
<i>Libinia dubia</i>							0.3			
TOTAL	0.6	0.8	0.2	5.5	71.4	13.6	7.9	0.6		5.2

1977										
	J	F	M	A	M	J	J	S	O	D
Cancer spp.					5.8	4.8	0.8	0.3		
<i>Ovalipes</i> spp.				4.5	205.3	40.8	5.8	1.3	200E	20.3
<i>Squilla empusa</i>					1.25	5.0		31.0	106	28.0
<i>Callinectes sapidus</i>										
<i>Carcinus maenas</i>						0.2	0.5			
<i>Homarus americanus</i>						0.8	0.5	0.3		
<i>Libinia dubia</i>										
TOTAL				4.5	212.4	51.6	7.6	1.9	306E	48.3

E = Estimated Count

period the number of *Cancer* individuals impinged has been small (average of 0 to 6 per 24 hours). The decrease in the impingement of *Cancer* since December 1975 does not appear to reflect any decrease in the population abundance of this species since, during 1977, *Cancer* was collected in trawls in relatively high abundances. Maximum impingement of the calico crab, *Ovalipes ocellatus*, and the mantis shrimp, *Squilla empusa*, occurred during October and November. During periods of peak impingement the average number of animals impinged per 24 hours ranged from 50 to over 250 for *Ovalipes* and 100 to 1200 for *Squilla*. *Ovalipes* was also impinged in lesser numbers during April, May and June when the average number of animals impinged per 24 hours ranged from 5 to 200. The magnitude of impingement of *Ovalipes* and *Squilla* has generally been consistent with trawl data. *Ovalipes* was collected in highest abundances in otter trawls during 1975 and 1977 while relatively few were collected during 1976. Similarly, highest numbers of *Ovalipes* were impinged during 1975 and 1977, while only moderate numbers were impinged in 1976. *Squilla* was collected in highest abundances during 1976 and impingement was also high during this year. Comparison of preoperational with operational trawl data shows no trends of decreasing catch abundance of *Cancer*, *Ovalipes* or *Squilla* as might be expected if excessive impingement had occurred.

In conclusion, with one exception, no major changes in epibenthic species abundance and distribution within New Haven Harbor have been apparent since the New Haven Harbor Station began operation (29 August 1975). Variations observed in species composition, distribution and abundance during all operational years appear to be well within the range of variability established by preoperational monitoring. The starfish, *Asterias forbesi*, was the only species that showed any major change in abundance; there has been no evidence to date that suggests that the observed annual decrease in catch abundance of this species was attributable to the operation of the New Haven Harbor Station. The operation of New Haven Harbor Station appears to have had no detectable influence on the epibenthic invertebrate community in New Haven Harbor.

LITERATURE CITED

- Berrill, M. and R. Stewart. 1973. Tunnel-digging in mud by newly-settled American lobsters, *Homarus americanus*. J. Fish. Res. Bd. Can. 30:285-287.
- Bigelow, H. B. and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildlife Serv., Fish. Bull. 74. 577 pp.
- Boddeke, R. 1975. Autumn migration and vertical distribution of the brown shrimp, *Crangon crangon* (L.), in relation to environmental conditions. Proc. 9th Europ. Mar. Biol. Symp. 1975. pp. 483-494.
- _____. 1976. The seasonal migration of the brown shrimp, *Crangon crangon*. Neth. J. Sea Res. 10:103-130.
- Caldwell, R. L. and H. Dingle. 1976. Stomatopods. Scientific American. 234(1):80-89.
- Crawford, E.A. and Homsher, P.J., DNA studies of a Chesapeake Bay population of the tunicate, *Molgula manhattensis*, (De-Kay) (Ascidacea). Chesapeake Sci., 16, 208 (1975).
- Davis, C.C. 1972. The effects of pollutants on the reproduction of marine organisms. p. 305-311 IN M. Ruivo (ed.). Marine pollution and sea life. Fishing News (Books) Ltd., London, England. 624 pp.
- Equitable Environmental Health, Inc. 1977. Port Jefferson Generating Station Final Aquatic Ecology Report. Prepared for Long Island Lighting Company. 110 pp.
- Galtsoff, P. S. 1964. The American oyster, *Crassostrea virginica*, (Gmelin). U.S. Fish and Wildl. Serv., Fishery Bulletin. 641:1-480.
- Gosner, K. L. 1971. Guide to identification of marine and estuarine invertebrates (Cape Hatteras to the Bay of Fundy). Wiley and Sons, Inc., New York, NY. 693 pp.
- Hanson, C. H., R. W. White and W. L. Hiram. 1977. Entrapment and impingement of fishes by power plant cooling water intakes: an overview. Marine Fisheries Review. 39(10):1-17.
- Jeffries, H. P. 1966. Partitioning of the estuarine environment by two species of *Cancer*. Ecol. 47(3):187-191.
- Kinne, O. 1970. Temperature - Invertebrates. pp. 407-513 IN O. Kinne (ed.). Marine Ecology. Volume I - Environmental Factors, Part I. Wiley - Interscience, New York. 681 pp.
- Krouse, J. S. 1972. Some life history aspects of the rock crab, *Cancer irroratus*, in the Gulf of Maine. J. Fish. Res. Bd. Can. 29:1479-1482.

- Logan, T. D. and D. Maurer. 1975. Diversity of marine invertebrates in a thermal effluent. Jour. Water Pol. Contr. Fed. 47(3):515-523.
- MacKenzie, C.L. 1970a. Oyster culture in Long Island Sound. U.S. Fish and Wildlife Service, separate No. 859.
- Marchant, A. and A. Holmsen. 1975. Harvesting Rock and Jonah crabs in Rhode Island: some technical and economic aspects. Resource Economics/NOAA Sea Grant. University of Rhode Island, Marine Memorandum Number 35. Kingston, R.I. 1975.
- McCluskey, W.J., Jr. 1978. Surface swarming of *Squilla empusa* Say (Stomatopoda) in Narragansett Bay, Rhode Island, U.S.A. Crustaceana.
- McLeese, D.W. and D.G. Wilder. 1958. The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. J. Fish. Res. Bd. Can. 15:1345-1354.
- Mitchell, R. Aspects of the ecology of the lamellibranch, *Mercenaria mercenaria*, (L.) in British waters. Hydrobiol. Bull., 8, 124 (1974).
- Musick, J.A. and J.D. McEachran. 1972. Autumn and winter occurrence of decapod crustaceans in Chesapeake Bight, U.S.A. Crustaceana, 22(2):190-200.
- National Academy of Sciences/National Academy of Engineering. 1973. Water Quality Criteria 1972. EPA-R3-73-033-March 1973.
- Normandeau Associates, Inc. 1972. Marine Sediments New Haven Harbor, Connecticut: Results of Analysis and Proposals for Dredge Spoil Disposal. Addendum 12 of Environment Report Coke Works Site, June, 1971. 134pp.
- _____. 1974. Stamford Harbor Ecological Studies, Stamford, Connecticut. Final Report 1971-1973 for the Northeast Utilities Service Company. 159pp.
- _____. 1974a. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report, 1972-1973 for The United Illuminating Company, New Haven, Connecticut. 215pp.
- _____. 1974b. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Interim Report, May - December 1973 for the United Illuminating Company, New Haven, Connecticut. 199pp.
- _____. 1975a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report, 1974 for The United Illuminating Company, New Haven, Connecticut. 223pp.
- _____. 1976a. New Haven Harbor Station Ecological Monitoring Studies New Haven Harbor, Connecticut. Annual Report, 1975 for The United Illuminating Company, New Haven, Connecticut. 312pp.

- _____. 1977a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1976 for The United Illuminating Company, New Haven, Connecticut. 376pp.
- _____. 1978a. New Haven Harbor Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1977 for The United Illuminating Company, New Haven, Connecticut. 359pp.
- Northeast Utilities Service Company. 1977. Annual Report. Millstone Nuclear Power Station Entrainment Studies Units 1 and 2.
- Price, K.S., Jr. 1962. Biology of the sand shrimp, *Crangon septemspinosa*, in the shore zone of the Delaware Bay Region. Ches. Sci. 3:224-255.
- Regnault, M. 1976. Influence of substratum on mortality and increment of shrimp *Crangon crangon*. Cahiers de Biologie Marine. 17:347-359.
- Richards, S.W. and G.A. Riley. 1967. Aspects of Oceanography of Long Island Sound. VI. The benthic epifauna of Long Island Sound. Bull. Bingham Oceanogr. Coll. 19(2):4-135.
- Saila, S.B. and S.D. Pratt. 1973. IN: Coastal and Offshore Environmental Inventory Cape Hatteras to Nantucket Shoals. S.B. Saila (coordinator). URI Marine Publication Series. p. 6.1-6.125.
- Scarratt, D.J., and R. Lowe. 1972. Biology of rock crab, *Cancer irroratus*, in Northumberland Strait. J. Fish. Res. Bd. Canada 29:161-166.
- Stewart, L.L. 1972. The seasonal movements, population dynamics and ecology of the lobster, *Homarus americanus*, off Ram Island, Connecticut. Ph.D. Thesis, Univ. of Conn.
- Talmage, S.S., and C.C. Coutant. 1978. Thermal Effects. Jour. Water Poll. Control Fed., 50:1514-1552.
- Thomas, M.L.H. 1969. Overwintering of American lobsters, *Homarus americanus*, in burrows in Biddeford River, P.E.I. J. Fish. Res. Bd. Can. 25:2725-2727.
- Turner, H.J. 1954. The edible crab fishery of Boston Harbor. Seventh report on investigations of the shellfisheries of Massachusetts. Woods Hole Oceanogr. Occ. Pap.
- Uziel, M.S. 1978. Impingement. Jour. Water Poll. Control Fed., 50:1553-1567.
- Williams, A. B. 1965. Marine decapod crustaceans of the Carolinas. Fish. Bull. 65:1-298.

Wilson, J.H., and Seed, R., Reproduction in *Mytilus edulis* L. (Mollusca: Bivalvia) in Carlingford Lough, Northern Ireland. Ir. Fish. Invest. Ser. B., 15, 1 (1974).

Winget, R.R., D. Maurer and H. Seymour. 1974. Occurrence, size composition and sex ratio of the rock crab, *Cancer irroratus* Say and the spider crab, *Libinia emarginata* leach in Delaware Bay. J. Nat. Hist. 8:199-205.

NEW HAVEN HARBOR
ECOLOGICAL STUDIES SUMMARY REPORT, 1979

9.0 OYSTER STUDIES
by David J. Hartzband and David N. Pease
Normandeau Associates, Inc.
Bedford, N. H.

TABLE OF CONTENTS

	PAGE
<i>INTRODUCTION.</i>	9-1
<i>METHODS</i>	9-5
1971-1973	9-5
1974-1977	9-6
<i>Hypothesis Testing.</i>	9-6
<i>RESULTS</i>	9-9
<i>Mortality</i>	9-9
<i>Change in Length (Growth)</i>	9-15
<i>DISCUSSION.</i>	9-19
<i>LITERATURE CITED.</i>	9-29
<i>STATISTICAL APPENDIX.</i>	9-34

LIST OF FIGURES

	PAGE
9-1. Oyster grounds in New Haven Harbor, Connecticut.	9-2
9-2. Oyster growth study measurements taken from May 1971 through November 1977 at (A) New Haven Harbor Station, (B) Long Wharf and (C) Fort Hale.	9-3
9-3. Dry weight condition indices with standard deviation range for control and experimental oysters, 1973-1977	9-10
9-4. Oyster survivorship (% survival) by month, 1973-1977.	9-11
9-5. Mean oyster lengths at Fort Hale and New Haven Harbor Station, May through December, 1972-1977.	9-12
9-6. Difference in adjusted final length versus adjusted mean length (mm) by station and year	9-16
9-7. Mean oyster-length by station, sampling period and year	9-18

LIST OF TABLES

	PAGE
9-1. MEAN LENGTH, DRY WEIGHT, DWCI, WWCI AND CAVITY VOLUMES OF OYSTERS FROM CONTROL, HARBOR STATION AND FORT HALE SAMPLES, 1973-1977.	9-7
9-2. PERCENT SURVIVAL OF OYSTERS AT NEW HAVEN HARBOR STATION AND FORT HALE: MAY-NOVEMBER, 1973-1977.	9-13
9-3. OYSTER MORTALITY DATA, 1974-1977.	9-14
9-4. OYSTER MORTALITY VERSUS YEAR AND STATION. RESULTS OF 3-WAY TESTS.	9-14
9-5. OYSTER MORTALITY VERSUS YEAR (G-TEST)	9-14
9-6. NET GROWTH (IN MM) OF OYSTERS HELD AT NEW HAVEN HARBOR STATION AND FORT HALE; MAY-NOVEMBER, 1972-1977.	9-16
9-7. NET GROWTH VERSUS YEAR; COVARIANCE ANALYSIS.	9-16
9-8. ADJACENT MONTHS DURING WHICH SIGNIFICANT* GROWTH OCCURRED.	9-17
9-9. CHLOROPHYLL α CONCENTRATIONS (mg/m^3) AT THE NEW HAVEN HARBOR STATION, 1974-1976.	9-20
9-10 NUMBERS OF <i>ASTERIAS FORBESI</i> COLLECTED DURING 10-MINUTE TRAWLS AT THE NEW HAVEN HARBOR STATION, 1974-1976.	9-22
9-11 CORRELATION ANALYSIS OF PERCENT SURVIVAL OF OYSTERS: 1973 VERSUS 1974-1977	9-23
9-12 CORRELATION PATTERNS FOR ALLOMETRIC VARIABLES BETWEEN STATIONS AND BETWEEN YEARS (1973-1977).	9-26

9.0 OYSTER STUDIES

by David J. Hartzband and David N. Pease
Normandeau Associates, Inc.
Bedford, N. H.

INTRODUCTION

New Haven Harbor has historically served as a natural source of seed oysters (*Crassostrea virginica*) for the Long Island Sound oyster fishery (Figure 9-1). The environmentally stressed conditions in the harbor presently necessitate the dredging and transferral of premarketable oysters (10-15 cm) to less impacted areas such as Oyster Bay, Northport Harbor, Peconic Bay and Gardiner's Bay, New York for "self-cleaning" (MacKenzie, 1970). The primary sources of environmental stress in New Haven Harbor are the extensive influx of domestic and industrial effluents, periodic oil spills and dredging (Army Corps of Engineers, 1973).

The objectives of oyster studies were to provide baseline information on oyster growth and condition in New Haven Harbor prior to start-up of New Haven Harbor Station and to assess the possible effects of the generating station's activities after operations commenced in July 1975 (commercial operations began 29 August).

These studies have been carried out in New Haven Harbor as part of the New Haven Harbor Station Environmental Monitoring Studies since 1971, four years prior to initiation of station operations. The 1971-1973 study was designed to monitor monthly change in length and weight of oysters held at three sites in New Haven Harbor: Fort Hale (C), New Haven Harbor Station (A) and Long Wharf (B) (Figure 9-2). New Haven Harbor Station pier was used as a study site to provide a base line for evaluation of possible near-field effects of the generating station's activities on existing inner harbor oyster growth and condition. The Long Wharf site was utilized as an inner harbor control, while the Fort Hale fishing pier site was utilized to identify typical patterns of oyster growth in the outer harbor where there could be expected to be

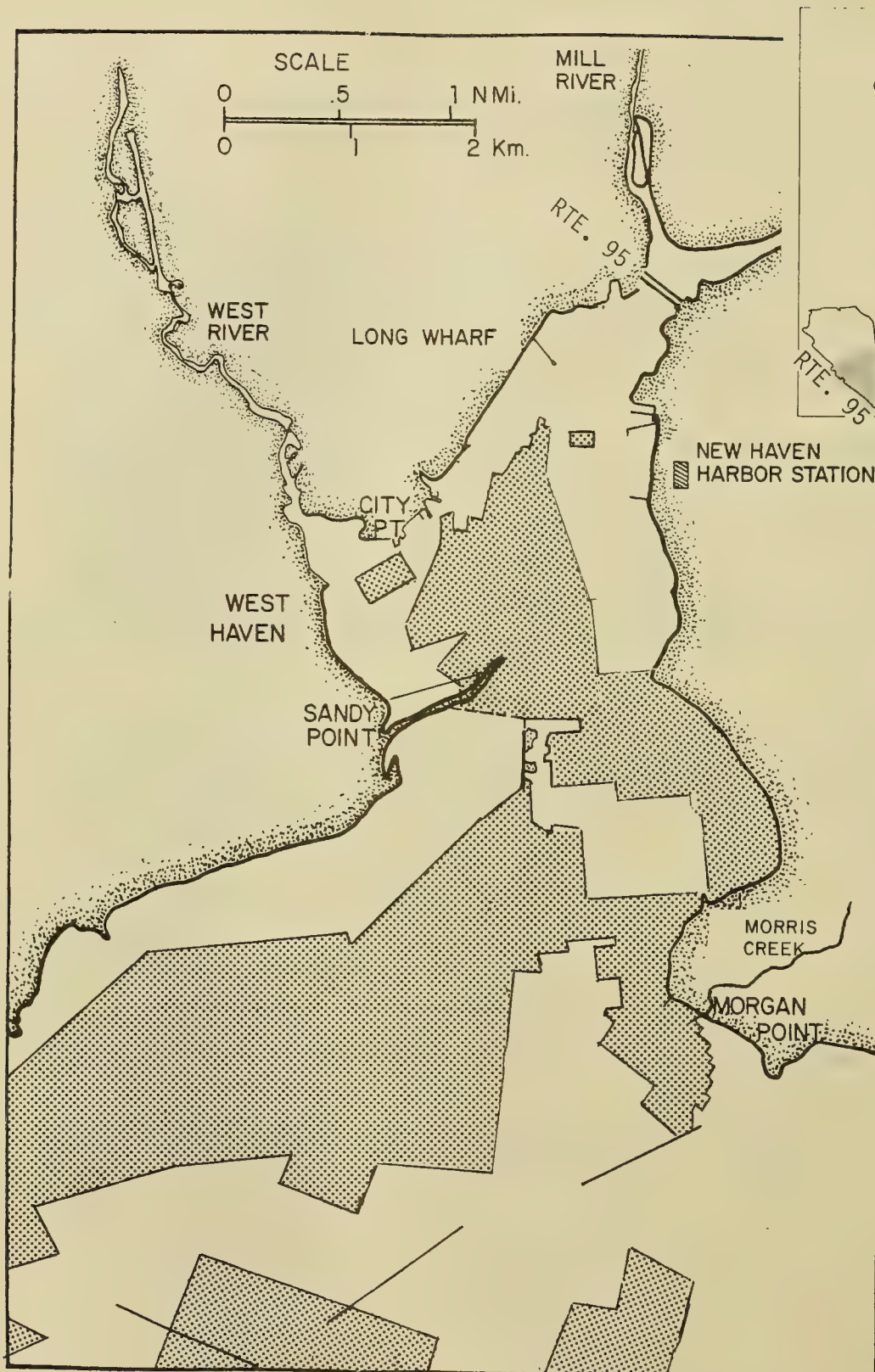


Figure 9-1. Oyster grounds in New Haven Harbor, Connecticut. New Haven Harbor Ecological Studies Summary Report, 1978.

Oyster Study Locations

1971	M J J A S O N D	
Harbor Station (A)	x x x x x x x x	
Long Wharf (B)	x x x x x x x x	
Fort Hale (C)	x x x x x x x x	
1972	J F M A M J J A S O N D	
Harbor Station (A)	x x x x x x x x x x	
Long Wharf (B)	x x x x x x x x x x	
Fort Hale (C)	x x x x x x x x x x	
1973	J F M A M J J A S O N D	
Harbor Station (A)	x x x x x	x
Long Wharf (B)	x x x x	
Fort Hale (C)	x x x x x	x
1974	J F M A M J J A S O N D	
Harbor Station (A)	x	x
Fort Hale (C)	x	x
1975	J F M A M J J A S O N D	
Harbor Station (A)	x x x x x x	
Fort Hale (C)	x x x x x x	
1976	J F M A M J J A S O N D	
Harbor Station (A)	x x x x x x x	
Fort Hale (C)	x x x x x x x	
1977	J F M A M J J A S O N	
Harbor Station (A)	x x x x x x x	
Fort Hale (C)	x x x x x x x	

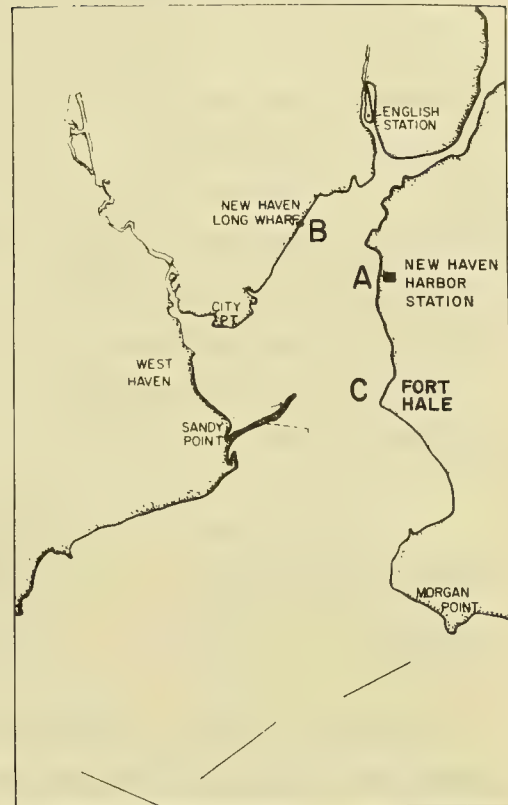


Figure 9-2. Oyster growth study measurements taken from May 1971 through November 1977 at (A) New Haven Harbor Station, (B) Long Wharf and (C) Fort Hale. New Haven Harbor Ecological Studies Summary Report, 1979.

relatively little if any effect of New Haven Harbor Station operation but where water quality and food availability would be generally similar.

The study was modified in May 1973. Oysters were purchased from New Haven Harbor instead of Marion, Massachusetts, where they previously had been obtained. Also, because of high oyster mortalities (up to 50% per month) not typical of the other two sites, Long Wharf was abandoned as a study site. More importantly, the program was revised to define the condition of the oysters, in addition to documenting changes in length. Condition index (CI), based on the relationship between the weight of the oyster meat to the volume of the shell cavity, is used as a measure of the quality of the meat but cannot be applied directly to growth (Galtsoff, 1964).

The operation of a generating station could potentially affect oyster growth and condition in New Haven Harbor by altering certain physical, chemical and biological parameters. The primary parameters that could be affected are temperature, dissolved oxygen, turbidity and food supply. Rather than design a series of experiments to determine the separate and combined effects of changes in these parameters on oyster biology, this study focused on the overall properties of oyster growth and mortality. By performing *in situ* experimental measurements of growth and mortality parameters, it was possible to formulate and test specific hypotheses that are directly applicable to the determination of the potential impact of the operation of New Haven Harbor Station on the growth and survival capabilities of oyster populations in the harbor.

Three hypotheses were developed with respect to these objectives and statistically tested to determine if any postoperational effects could be delineated and attributed to the activity of New Haven Harbor station. These hypotheses were: 1) mortality differs by station or by year; 2) net change in length (growth) varies by station or by year and 3) seasonal growth patterns differ at the two stations. It was possible to test only a corollary hypothesis of 3) namely: length changes at the two experimental stations occur in the same time periods

for a given year. In addition, growth, mortality and condition index were compared graphically to determine if postoperational changes in patterns could be detected. Appropriate data sets were used for hypothesis testing while the entire data set (1972-1977) was used for graphic comparisons.

METHODS

A brief, general resume of sampling and measurement methodologies for each of the two overall experimental periods (May 1971-April 1973 and May 1973-November 1977) follows. For detailed methods, analytic techniques, and specific results for each year's study, refer to the relevant Normandeau Associates, Inc. reports (NAI: 1973, 1974a, 1974b, 1975, 1976, 1977, 1978).

1971 - 1973

Trays of live oysters were emplaced in July 1971 at the Fort Hale fishing pier, the outer end of the Harbor Station pier and on Long Wharf (Figure 9-2). At each site, a wire basket containing trays of oysters was attached to the pier in such a position that it would remain submerged at all tidal levels (approximately six feet below mean low water). Trays were separated into two sections. The larger part contained 50 measured and weighed oysters. The remaining portion of the basket held a reserve supply of oysters to be added to the study group as mortality replacements. These oysters were purchased from oyster growers in Marion, Massachusetts, and had been grown on the west side of Buzzard's Bay. Once each month, the trays were raised and all oysters scraped clean of fouling growth. Each living specimen was measured with calipers along its greatest length and weighed (Ohaus spring scale) in a mesh basket immersed in a pail of harbor water.

The August 1971 inspection of the oyster baskets revealed that the Fort Hale sample had been vandalized, and all oysters removed. The

tray was therefore moved to a less accessible dolphin offshore from the Fort Hale pier and restocked with a new sample in September 1971. In May 1972 all remaining oysters at all stations were discarded and replaced with new specimens, also from the Marion, Massachusetts, area. The experiment was then continued until April 1973.

1974 - 1977

Starting in 1973 a bushel of oysters was purchased from Long Island Oyster Farms in New Haven, in May or June of each sampling year. About 200 oysters of various lengths were selected and divided by a random sampling technique into three portions. One hundred and fifty were numbered with identification tags, measured and 75 each placed in trays at Harbor Station and Fort Hale. Fifty oysters were returned to the laboratory to serve as initial controls. The following measurements were taken: shell length, total volume (by displacement) and air weight of intact oyster, volume and dry weight of shells, volume and wet and dry weight of meat. The condition index (CI) was calculated by dividing oyster meat weight by the shell cavity volume (total oyster volume minus the volume of shells) and multiplying the quotient by 100 (Galtsoff, 1964). Oyster lengths were measured at the beginning and end of the experiment in 1974 and monthly during the experiment in 1975-1977. Harbor Station and Fort Hale oysters were sacrificed at the end of each experimental year and subjected to the same volume and weight measurements (Table 9-1).

Hypothesis Testing

The data acquired by these methods were used each year to make statistical comparisons between stations and to test the validity of the three summary hypotheses as here described. Hypothesis (1) mortality differs by station or by year, was tested with a series of 3-way G-tests (Sokal and Rohlf, 1969). Factors were a) stations, b) years

TABLE 9-1. MEAN LENGTH, DRY WEIGHT, DWCI, WWC I AND CAVITY VOLUMES OF OYSTERS FROM CONTROL, HARBOR STATION AND FORT HALE SAMPLES, 1973-1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	ORIGINAL CONTROL						HARBOR STATION						FORT HALE					
	MAY 1973	MAY 1974	JUN 1975	MAY 1976	JUN 1977		DEC 1973	DEC 1974	NOV 1975	NOV 1976	NOV 1977		DEC 1973	DEC 1974	NOV 1975	NOV 1976	NOV 1977	
N	50	50	48	50	50		66	56	51	67			70	58	50	64		
Mean Length (mm)	89.2	92.7	92.8	82.7	66.5		91.6	93.9	100.6	102.8	87.3		99.0	100.4	105.5	100.3	84.7	
S	4.3	6.2	15.1	6.3	4.9		6.9	7.2	12.8	7.6	6.4		8.5	7.5	14.2	8.8	5.1	
Dry Weight (gm)	2.2	3.3	2.6	3.3	1.3		1.9	2.8	4.3	3.6	1.8		3.3	5.0	6.3	5.1	2.9	
S	0.6	0.8	1.4	0.5	0.3		0.6	0.7	0.8	0.9	0.5		0.9	1.1	1.4	1.2	0.7	
DWCI	8.9	10.9	8.5	15.6	10.4		7.5	9.9	14.6	10.4	6.9		11.0	14.7	16.0	14.9	11.6	
S	3.2	3.3	3.4	8.5	4.5		2.4	4.3	6.0	4.9	2.6		3.7	5.9	5.3	3.8	2.6	
WWCI	53.3	48.9	40.3	46.8	51.8		43.4	42.2	45.6	53.6	28.8		55.5	53.2	48.3	60.2	43.2	
S	16.9	12.9	14.5	25.5	23.6		11.5	17.3	18.5	24.7	10.8		19.6	24.3	14.8	16.4	8.5	
Cavity Volume (ml)	27.0	32.6	30.5	27.1	14.4		27.3	31.3	35.7	40.6	27.3		32.8	36.2	43.	35.2	24.7	
S	8.4	10.3	12.5	13.1	6.2		8.2	11.3	18.0	18.2	6.6		12.8	10.6	18.2	9.7	4.4	
Wet Weight	13.4	14.9	12.0	9.9	6.3		11.2	11.8	13.9	18.3	7.5		16.6	17.6	19.1	20.3	10.6	
	3.4	3.0	5.6	1.9	1.3		2.6	2.8	3.6	3.9	1.9		4.2	3.8	4.5	4.3	2.4	

(1974-1977) and c) mortality. The analysis was carried out with respect to total number of oysters, live oysters and dead oysters. Total number of oysters reflected the number known to be alive, the number known to be dead and the number of oysters with missing tags but known to be alive. Missing oysters were considered dead except when untagged oysters were not noted, (as in 1975). In this latter case, all missing oysters were excluded from the analysis as were oysters whose status was questionable. Tests of this hypothesis used a per experiment alpha level of 0.05.

Hypothesis (2) net change in length (growth) varies by station or by year, was tested by means of a covariance analysis (Guenther, 1964). The covariate or "concomitant" variable in this analysis was initial length and the dependent variable was final length. The independent classification variables were stations and years. Data were treated as a 2-factor, completely randomized design with one concomitant variable. Scheffe's method for multiple comparison (Scheffe, 1969) was employed when so indicated by the results of the ANOVA (Analysis of Variance). Additionally, because of problems of heterogeneity of variances (see statistical appendix), three independent covariance analyses were used to assess station variation within years. Factors were a) stations and b) initial length (covariate). No transformation was applied to the data set because none were consistently successful in normalizing the variance for the entire data set. Data included all oysters for which initial and final lengths were recorded.

Hypothesis (3) length changes at the two experimental stations occur in the same time periods for a given year, was tested with a mixed model randomized block ANOVA for each station within each year (Kirk, 1968; Gill, 1977). Tukey's procedure for multiple comparisons was used to assess mean length differences by months. When variances were heterogeneous, modified Tukey's procedures were used. Comparison of growth patterns were assessed based on differences in results for the two stations. Data included all oysters that were measured in all months.

These hypotheses were indirectly addressed with respect to the entire data set (1971-1977) by means of graphic comparisons between stations and between years (Figures 9-3, 9-4 and 9-5). This was especially important for hypotheses 2 and 3 where the nature of the data precluded the inclusion of preoperation results in the formal hypothesis testing (see Statistical Appendix).

RESULTS

Table 9-1 gives mean length, dry weight, dry weight condition index, wet weight condition index and cavity volumes for control and experimental oysters from 1973 - 1977, while Figure 9-3 graphs dry weight condition index of control and experimental oysters for the same time period. These summary data are presented for perspective and to temporarily extend the results of hypothesis testing.

Mortality

Figure 9-4 graphs percent survival of oysters by month from 1973 to 1977, while Table 9-2 presents the data with summary statistics from which these graphs were developed. These data show that percent survival (the complement of percent mortality) appeared similar in all years (range 80-96%) except 1975 when percent survival dropped to 67-69%.

Table 9-3 displays oyster mortality data from 1974-1977. These data were used to test hypothesis (1), with regard to differences in mortality attributable to station and year. Table 9-4 presents the results of hypothesis testing for mortality versus year and station, and Table 9-5 presents the results of a pairwise comparison of years, two years at a time. The results shown in Table 9-4 indicate that oyster mortality was independent of station but dependent upon year. The mortality by station by year interaction was not significant. The

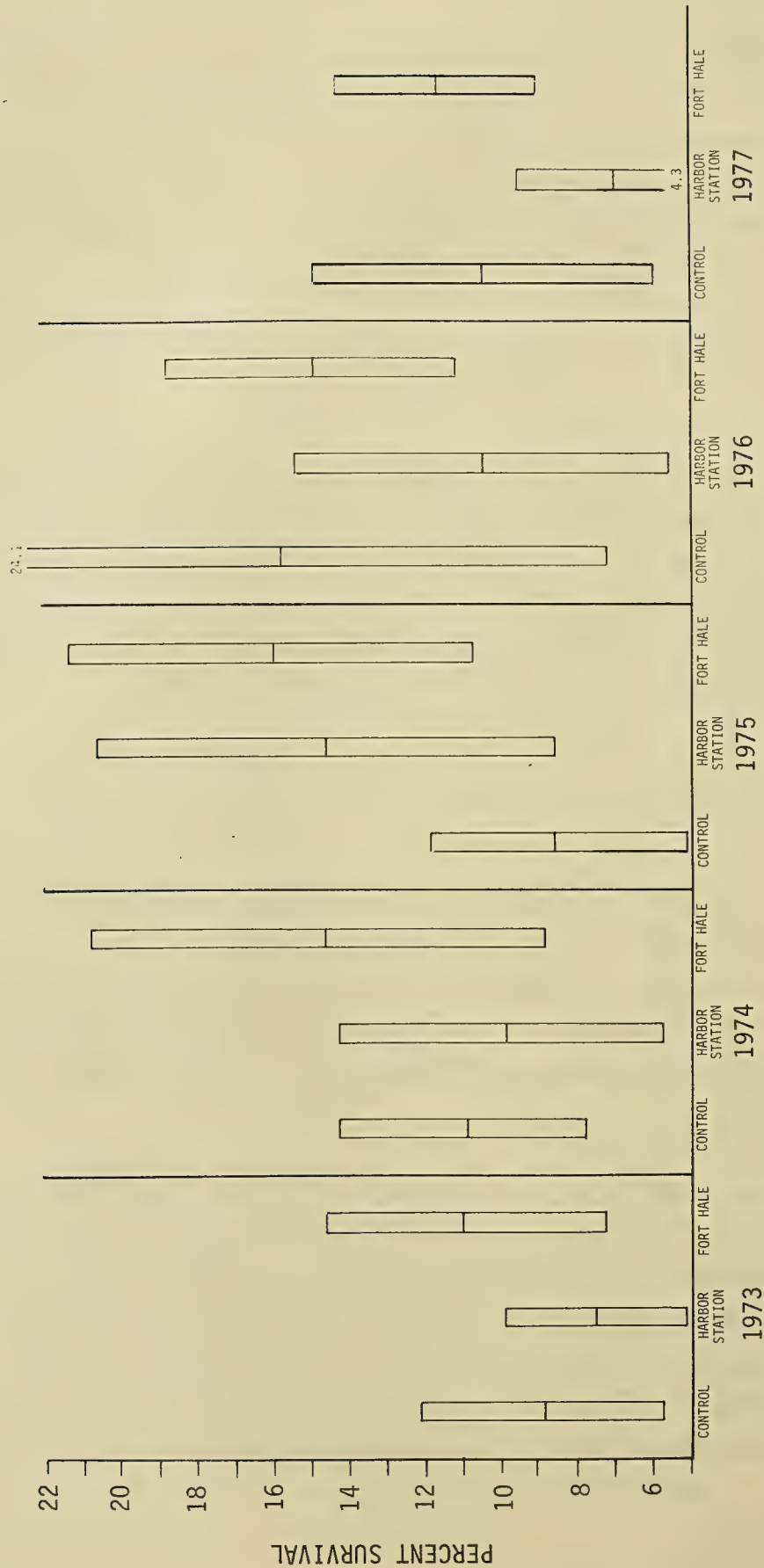


Figure 9-3. Dry weight condition indices with standard deviation range for control and experimental oysters, 1973-1977. New Haven Harbor Ecological Studies Summary Report, 1979.

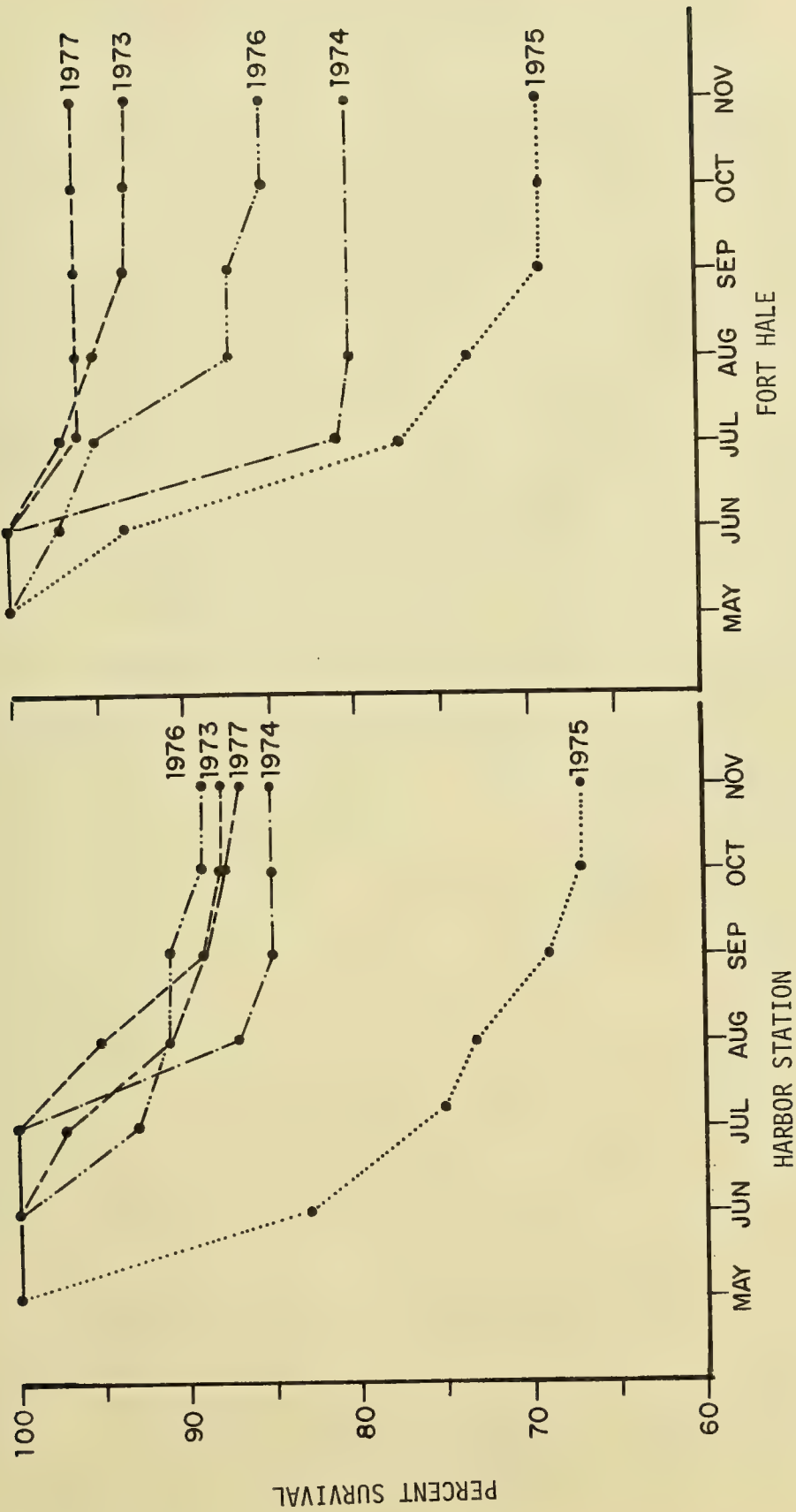


Figure 9-4. Oyster survivorship (% survival) by month, 1973-1977. New Haven Harbor Ecological Studies Summary Report, 1979.

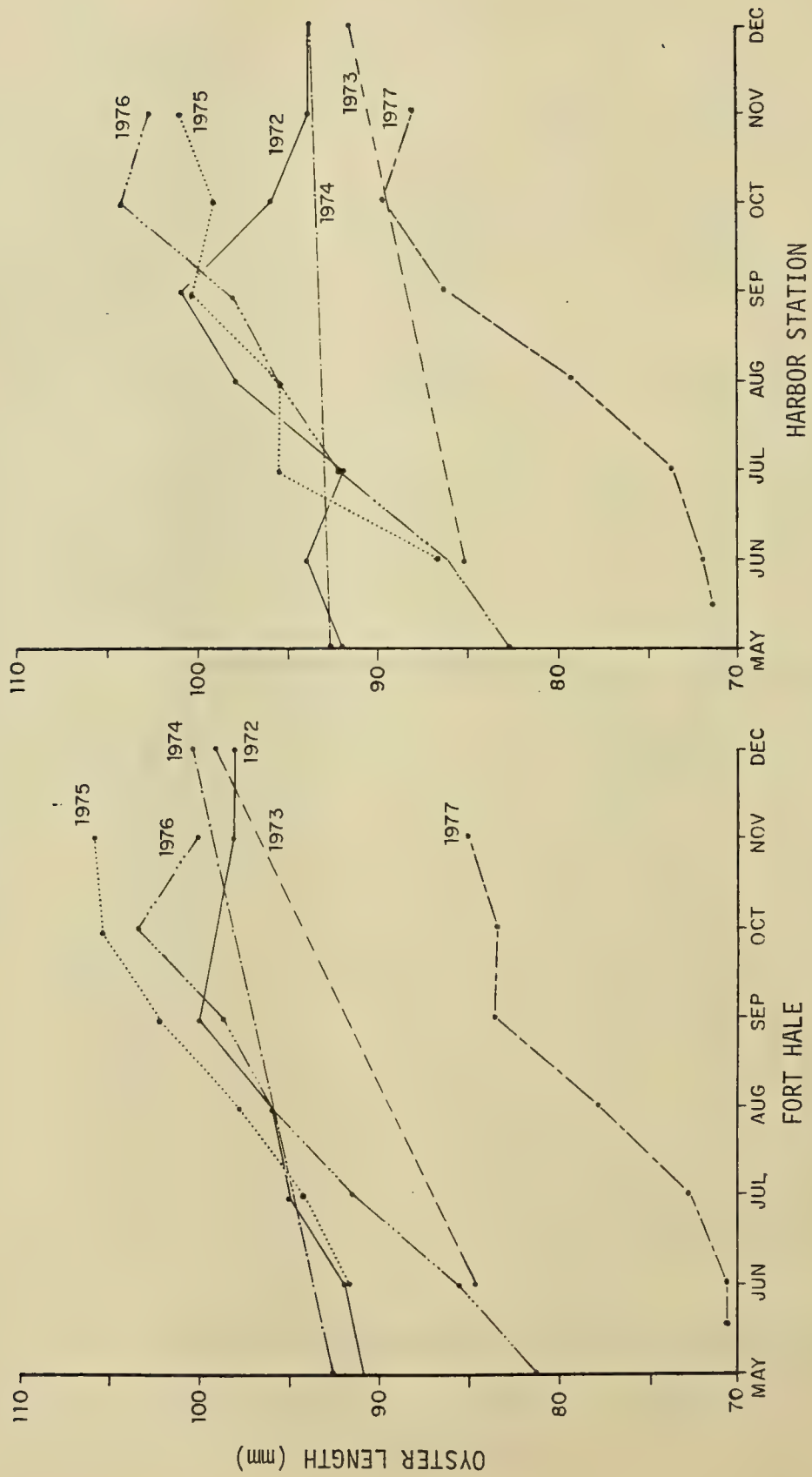


Figure 9-5. Mean oyster lengths at Fort Hale and New Haven Harbor Station, May through December, 1972-1977. New Haven Harbor Ecological Studies Summary Report, 1979

TABLE 9-2. PERCENT SURVIVAL OF OYSTERS AT NEW HAVEN HARBOR STATION AND FORT HALE: MAY-NOVEMBER, 1973-1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	HARBOR STATION							FORT HALE							HS	FH
	1973	1974	1975	1976	1977	$\bar{x}$	s	1973	1974	1975	1976	1977	$\bar{x}$	s	$\bar{x}$	s
MAY		100	100	100		100	---		100	100	100		100	---	100	---
JUNE	100	100	83	100	100	97	7.6	100	100	93	97	100	98	3.1	97	5.5
JUL	100	100	75	93	97	93	10.5	97	81	77	95	96	89	9.4	91	9.6
AUG	95	87	73	91	92	88	8.6	95	80	69	87	96	86	9.8	87	8.3
SEP	89	85	69	91	89	85	9.0	93	80	69	87	96	85	10.8	84	9.5
OCT	88	85	67	89	88	83	9.3	93	80	69	85	96	85	10.8	84	9.5
NOV	88	85	89	87	83	9.2	93	80	69	85	96	85	85	10.8	84	9.5

$\bar{x}$ = mean

s = standard deviation

TABLE 9-3. OYSTER MORTALITY DATA, 1974-1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

		LIVE	DEAD	TOTAL
1974	Fort Hale	58	16	74
	Harbor Station	54	14	68
	Total	112	30	142
1975	Fort Hale	50	23	73
	Harbor Station	50	22	72
	Total	100	45	145
1976	Fort Hale	64	11	75
	Harbor Station	65	9	74
	Total	129	20	149
1977	Fort Hale	43	2	45
	Harbor Station	65	10	75
	Total	108	12	120
1974- 1977	Fort Hale	215	52	267
	Harbor Station	234	55	289
	Total	449	107	556

TABLE 9-4. OYSTER MORTALITY VERSUS YEAR AND STATION. RESULTS OF 3-WAY TESTS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1978.

HYPOTHESIS TESTED	DEGREES OF FREEDOM	G
Mortality x Station x Year	10	32.98*
Station x Year	3	6.98
Mortality x Year	3	23.01*
Mortality x Station	1	0.02
Mortality x Station x Year	3	2.98

TABLE 9-5. OYSTER MORTALITY VERSUS YEAR (G-TEST). NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1978.

YEARS	HYPOTHESIS	DEGREES OF FREEDOM	G
1974, 1975	Mortality x Year	1	3.67
1974, 1976	Mortality x Year	1	3.05
1974, 1977	Mortality x Year	1	6.19
1975, 1976	Mortality x Year	1	13.50*
1975, 1977	Mortality x Year	1	18.29*
1976, 1977	Mortality x Year	1	0.75

* Result significant, per experiment $\alpha = 0.05$.

results shown in Table 9-5 indicate that mortality in 1976 and 1977 was significantly lower than mortality in 1975.

Change in Length (Growth)

Figure 9-5 shows mean oyster length by month at each station during the period 1974-1977, and Table 9-6 shows net growth (mm) of oysters at each station during the same time period. These data appear to indicate that net growth was high at both stations in 1975, 1976 and 1977 although mean length was low in 1977. Net growth in Table 9-6 has not been adjusted for initial length as was done in the covariance analysis test of hypothesis (2). Table 9-7 expresses the results of the test of this hypothesis (see statistical appendix) as a series of inequalities relating adjusted net growth and year, while Figure 9-6 compares the pattern of growth by station and by year. These results indicate that growth at both stations was greatest in 1976, least in 1977 and intermediate in 1975. Thus, yearly variation was highly significant but between-station variation was not. The station-by-year interaction was not significant at a nominal alpha level of 0.05.

Within-year growth patterns (Hypothesis (3)) were tested using a complex analysis of variance technique with pairwise multiple comparisons to determine those months between which mean length differed significantly. Table 9-8 and Figure 9-7 show the results of this analysis. The multiple comparisons showed that significant growth took place during the same time periods at both experimental stations in 1975, 1976 and 1977 with the exception that in 1975 the first significant growth increase took place one month later at Fort Hale than at Harbor Station.

TABLE 9-6. NET GROWTH (IN MM) OF OYSTERS HELD AT NEW HAVEN HARBOR STATION AND FORT HALE; MAY-NOVEMBER, 1972-1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

HARBOR STATION								$\bar{x}$ = Mean length s = Standard deviation	
1972	1973	1974	1975	1977	$\bar{x}$	s			
9.0	6.4	13.9	20.3	15.8	11.1	6.9			

FORT HALE								HS & FH	
1972	1973	1974	1975	1976	1977	$\bar{x}$	s	$\bar{x}$	s
9.0	14.4	7.7	13.9	18.8	14.1	13.0	4.0	12.0	5.5

TABLE 9-7. NET GROWTH VERSUS YEAR; COVARIANCE ANALYSIS. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

1976, 1975 > 1977 ($P < 0.001$, experimentwise)

1976 > 1975 ($0.001 < P < 0.005$, experimentwise)

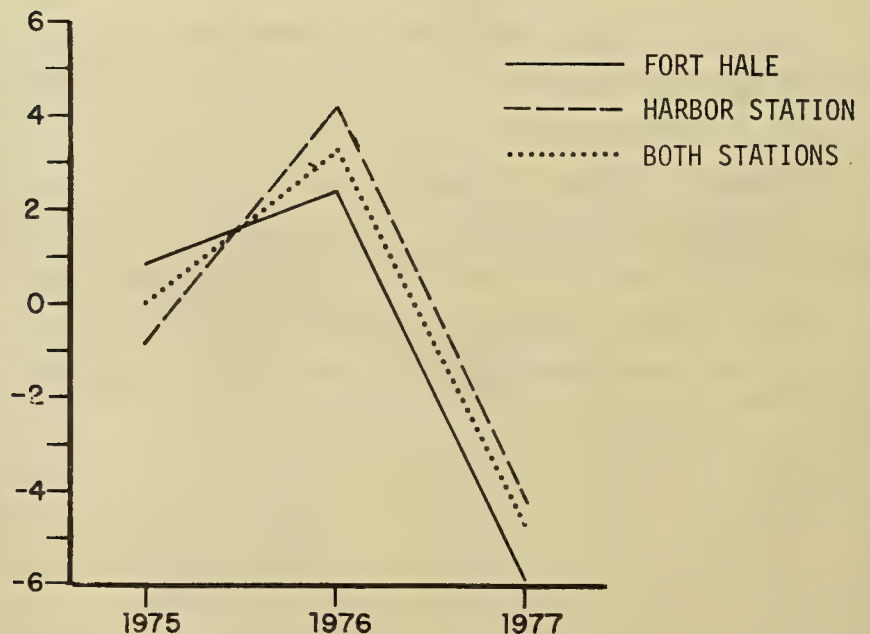


Figure 9-6. Difference in adjusted final length versus adjusted mean length (mm) by station and year. New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 9-8. ADJACENT MONTHS DURING WHICH SIGNIFICANT* GROWTH OCCURRED.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

1975 HARBOR STATION

Jul > Jun

Sep > Aug

FORT HALE

Aug > Jul

Sep > Aug

1976 HARBOR STATION

Jun > May

Jul > Jun

Aug > Jul

Sep > Aug

Oct > Sep

FORT HALE

Jun > May

Jul > Jun

Aug > Jul

Sep > Aug

Oct > Sep

1977 HARBOR STATION

Aug > Jul

Sep > Aug

FORT HALE

Aug > Jul

Sep > Aug

* At experimentwise $\alpha = 0.05$.

FORT HALE ——— F Growth at Fort Hale between indicated month and previous month was significant ($\alpha_E = .05$)
 HARBOR STATION - - - - H Growth at Harbor Station between indicated month and previous month was significant ($\alpha_E = .05$)

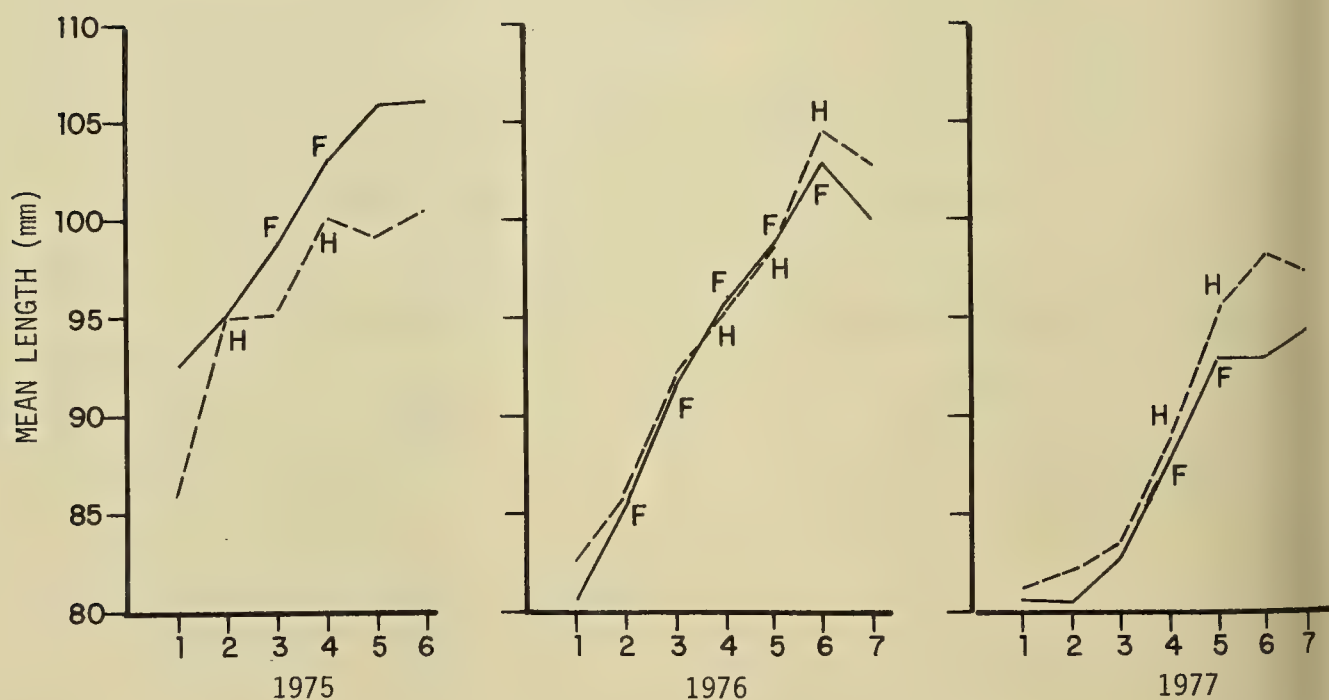


Figure 9-7. Mean oyster-length by station, sampling period and year. New Haven Harbor Ecological Studies Summary Report, 1979.

DISCUSSION

Much work has been done on the biology of *Crassostrea virginica*, but little of it deals with the hypotheses and variables that have been addressed in this study. Most of this historical work has dealt with the commercial aspects of oyster development and culture (MacKenzie, 1970a, b, 1977a, b; Loosanoff, 1932, 1965, 1966). Galtsoff (1964) summarized the knowledge of oyster biology and included a section in his monograph on the effect of "pollution" on oyster populations. Many recent investigations focus on the effect of changes in specific physical or chemical parameters on oyster populations (Davis, and Calabrese, 1964; Lough, 1975; Frazier, 1975; Diaz, 1968). As previously described, this study investigates the potential impact of the operation of an electric generating station on oyster growth and mortality in New Haven Harbor. Three factors are discussed below with respect to the determination of possible pre- and post-operational effects of the New Haven Harbor Station, and in relation to the hypotheses and variables of this study. These factors are mortality, growth and condition index.

Mortality was statistically analyzed for the years 1974-1977 and found to be independent of station but dependent on year. This indicates that differing environmental conditions at the two experimental sites, including any environmental modification due to the operation of New Haven Harbor Station, had no effect on overall oyster mortality. Mortality was significantly higher in 1975 at both sites than in any other year tested. This may have been associated with the low condition indices observed in the initial control oysters in 1975 (Table 9-1). Since mortalities were high in June and July (Figure 9-4) it is possible that the oysters purchased were not as healthy as in previous years, and thus were more easily subject to disease or predation. Data from several other program elements were examined to determine if there was any correlation between the observed high oyster mortality in 1975 and variations in occurrence of known predators or food supply. Table 9-9 shows monthly measurements of chlorophyll a for 1974-1976 at Harbor Station. The patterns for all three years are quite

TABLE 9-9. CHLOROPHYLL *a* CONCENTRATIONS (mg/m³) AT THE NEW HAVEN HARBOR STATION, 1974-1976. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

MONTH	TIDE	1974	1975	1976
January	ebb	0.82	1.70	2.10
	flood	1.48	2.00	2.30
February	ebb	1.78	0.90	13.20
	flood	1.57	1.00	4.40
March	ebb	1.94	4.60	11.20
	flood	1.74	3.70	10.90
April	ebb	12.91	22.20	38.40
	flood	26.39	14.80	10.90
May	ebb	11.24	3.00	16.00
	flood	21.78	8.70	10.10
June	ebb	10.31	1.90*	43.60
	flood	10.06	1.10*	52.00
July	ebb	59.37	1.40*	NS
	flood	38.74	1.40*	15.30
August	ebb	5.88	3.60	10.50
	flood	46.76	5.90	19.60
September	ebb	4.59	6.10	20.80
	flood	5.42	5.60	17.10
October	ebb	2.00	7.60	4.60
	flood	7.70	2.80	2.90
November	ebb	1.70	5.50	3.60
	flood	2.90	3.40	7.10
December	ebb	2.30	0.90	2.40
	flood	3.80	1.50	NS

* Anomalous data

NS = No sample

similar except for anomalously low concentrations in the June, July and August, 1975 data. Phytoplankton total cell counts were not correspondingly low and chlorophyll data for this time period are suspect (see Section 4). It therefore does not seem likely that low food supply was the cause of the observed high mortality. The only known predator of adult oysters found in great numbers near Harbor Station (epibenthic trawl station 8) was the seastar *Asterias forbesi* which was occasionally found in the experimental trays. Table 9-10 shows the monthly occurrence of *A. forbesi* in epibenthic trawls at Harbor Station from 1974-1976. The greatest densities of seastars, May-October 1974, were not correlated with the highest oyster mortalities, May-July 1975. It does not seem likely that predation was the cause of the observed high mortality, but that poor initial health as indicated by low condition indices was.

Table 9-2 indicates percent survival of oysters by month at both Harbor Station and Fort Hale during the period 1973-1977. Data from 1973 were not included in the hypothesis testing analysis because time periods during which measurements were taken were different than in subsequent years. However, a correlation analysis ($\alpha = 0.05$) shows that monthly change in percent survival at both experimental stations was very similar for 1973 and all subsequent years. Table 9-11 gives correlation coefficient (r) values for 1973 versus all subsequent years at both Harbor Station and Fort Hale. These values ranged from 0.77 (1975, Harbor Station) to 0.97 (1977, Harbor Station; $r_{0.05} = 0.4$). These results imply that the same pattern of mortality was exhibited in 1973 as in subsequent years, i.e., mortality was not significantly different between stations ($r = 0.97$, $\alpha = 0.01$), mortality was significantly higher in 1975 than in 1973 ($r = 0.77$, $r_{0.05} = 0.84$) and mortality was similar between years 1973 and 1974, 1976, 1977. These results corroborate the conclusions of the tests of hypothesis 1) that pre- and postoperational mortalities were similar and that no effect can be discerned on oyster mortality with respect to the operation of New Haven Harbor Station.

TABLE 9-10. NUMBERS OF *ASTERIAS FORBESTI* COLLECTED DURING 10-MINUTE TRAWLS AT THE NEW HAVEN HARBOR STATION, 1974-1976. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	1974	1975	1976
January	0	250	26
February	0	240	12
March	13	60	90
April	0	24	12
May	2250	216	39
June	660	260	20
July	515	66	94
August	496	240	3
September	530	176	6
October	408	214	29
November	160	45	68
December	46	50	30

TABLE 9-11. CORRELATION ANALYSIS OF PERCENT SURVIVAL OF OYSTERS: 1973 VERSUS 1974-1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	HARBOR STATION 1973	FORT HALE 1973
1974	0.93	0.90
1975	0.77*	0.96
1976	0.86	0.97
1977	0.97	0.83

* Value shows nonsignificant correlation -- all other values significant.
 $r_{0.05} = 0.84$

Dame (1972) reported that allometric relationships for subtidal and intertidal oyster populations (North Inlet, Georgetown, South Carolina) varied with oyster size. He further speculated that local environmental conditions such as tidal range, wave action and water chemistry might be important in determining shell weight/dry body weight ratios and other growth relationships in oyster populations. In light of Dame's findings and speculation it was necessary that any test of a hypothesis with respect to oyster growth take into account differences due to initial size and also make evident distinctions between areas of potentially different environmental conditions (stations). The covariance analysis carried out to test hypothesis (2) met these criteria. This analysis utilized data from 1975-1977 and showed that yearly variation in net growth was highly significant but that between-station variation was not (minimum, $0.001 < P < 0.005$).

The patterns of mean net oyster growth by month between Fort Hale and Harbor Station for the years 1973 - 1977 were not significantly different (Spearman's rank correlation test, $P=0.66$, $P_{0.05}=0.55$; Conover, 1971). There was, however, significant variation in mean net growth between years 1973-1977 (Kruskal-Wallis test, $T=430.6$, $T_{0.05}=19.7$; Conover 1971). The results of both the Spearman's rank correlation and Kruskal-Wallis test on the extended data set corroborate the results of the covariance analysis.

The potential relationship between allometric measurements and environmental parameters that affect oyster growth suggested a method for including those allometric measurements not used in the formal hypothesis testing analysis. If similar environmental conditions are reflected in similar allometric relationships then similar environmental conditions should be reflected in patterns of correlation between any two of the allometric relationships. More specifically, similar environmental conditions should produce similar patterns of correlation between cavity volume and mean length or any two allometric parameters. Mean length, cavity volume, wet weight and dry weight measurements from this study (1973-1977) were assembled into matrices by year and by station.

Each pair of parameters was then correlated (Spearman's rank correlation test, Conover, 1971). The results of this correlation analysis are shown in Table 9-12. Correlation patterns between these allometric parameters are very similar for Harbor Station and Fort Hale experimental groups over all years combined. This is indicated by the fact that all correlation values for these parameters between station are positively significant. It is clear, however, that correlation patterns between years are not similar. If, as Dame suggests, oyster growth is contingent upon local environmental conditions, these results imply that environmental conditions which are relevant to oyster growth were similar at both stations during pre- and post-operational periods. These results temporarily extend the conclusions of the ANOVA.

Table 9-1 and Figure 9-3 show the patterns of condition indices for control and experimental oysters. Figure 9-3 shows that in all instances dry weight condition indices were lower at Harbor Station than at Fort Hale, and that in all but one instance (1975) condition indices at Harbor Station were lower than in the initial controls. During 1975 initial control oysters had low condition indices, a factor probably reflected in the high initial mortality at both stations. Condition index was first expressed by Grave (1912) as the quality or fatness of oysters measured as the volume of space enclosed by the two valves actually occupied by oyster meat. Hopkins (1949) suggested that the ratio of dry weight of oyster meat (G) $\times$ 100 divided by cavity volume (ml) be used as the condition index. Butler (1949) states that condition indices for *C. virginica* range from 1 to 17 with 10 indicating a marketable oyster. Finally Galtsoff (1964) standardized the measurement of cavity volume by displacement of water.

Few studies have used condition index as a measure of the health of oyster populations. Galtsoff (1964) and Ogle *et al.* (1977) noted that measurements of condition index have a seasonal pattern which is influenced by time of spawning and amount of food available. Condition is generally low after spawning but then builds up as glycogen is

TABLE 9-12. CORRELATION PATTERNS FOR ALLOMETRIC VARIABLES BETWEEN STATIONS AND BETWEEN YEARS (1973-1977). NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

Harbor Station		Mean Length (ml)	Cavity Volume (cv)	Wet Weight (ww)	Dry Weight (dw)		Mean Length (ml)	Cavity Volume (cv)	Wet Weight (ww)	Dry Weight (dw)
	1973									
	ml					ml				
	cv	0.98				cv	0.50			
	ww	1.0	0.98			ww	0.99	0.50		
	dw	1.0	0.98	1.0		dw	0.99	0.99	0.99	
Fort Hale	ml					1974	ml			
	cv	1.0				cv	0.87			
	ww	1.0	1.0			ww	0.87	1.0		
	dw	0.90	0.90	0.90		dw	0.5	0.87	0.87	
P 0.05, $\rho = 0.2, ---, 0.8$						1975	ml			
						cv	0.50			
						ww	0.0	0.50		
						dw	-0.50	0.87	0.87	
						1976	ml			
						cv	0.76			
						ww	1.0	0.50		
						dw	-0.76	-0.50	-0.76	
						1977	ml			
						cv	1.0			
						ww	0.99	0.99		
						dw	1.0	0.99	1.0	

P 0.05, $\rho = 0.1, ---, 0.9$

built back up in the tissues. In a study of condition of *C. virginica* from Pearl Harbor, Hawaii, Sakuda (1966) found a typical seasonal pattern with high values during December, January and February (CI=6-7.7) and low values during June, July and August (CI = 2-4). He attributed the very low condition indices of oysters from some beds to unfavorable environmental conditions, primarily excessive silting. Ogle *et al.* (1977) in a transfer experiment designed to detect the effect of depth on oyster growth also determined a seasonal pattern for condition index e.g., high in June 1973 (13.2-15.5); low in December, 1973 (5.0-7.0) higher in March 1974 (7.9-10.8) and low in June 1974 (1.3-2.2). The authors explain the high condition indices in June of 1973 as due to a lack of spawning because of transfer.

Dry weight condition indices in this study ranged from 8.5 to 15.6 in May/June for initial controls to 6.9-14.6 in November/December at Harbor Station and 11.0-16.0 in November/December at Fort Hale. These condition indices are generally higher than those in the studies of both Sakuda (1966) and Ogle *et al.* (1977). Seasonal patterns are not as well defined in the New Haven data because of the range of condition indices recorded. Low condition indices at Harbor Station relative to Fort Hale were consistently low both during pre- (1973-1974) and post- (1976-1977) operational studies at the Harbor Station site. It is therefore likely that these low indices are more a reflection of the greater environmental impact in the inner harbor from various sources other than from plant operation. In 1967 the FWQA conducted water quality investigations in New Haven Harbor and concluded that the inner harbor area was grossly polluted. They measured dissolved oxygen levels of 4.0 mg/l and total and fecal coliform densities in excess of 10^5 and $3.6 \times 10^4/100$ ml, respectively. Data from the current study indicate a range of dissolved oxygen measurements in the harbor of 2.5-14.5 mg/l. Even in the outer harbor total coliform counts were above standards and sewage sludge deposits exceeding 6 inches in depth were prevalent in the area (reported in Army Corps of Engineers, 1973). Laboratory tests have shown oysters to take up 2.5-5.0 mg/hr of oxygen (Galtsoff, 1964), so it is possible that at some concentrations recorded in New Haven Harbor this rate of uptake could not be maintained. As filter feeders, oysters

take up and accumulate coliform bacteria in their bodies. These bacteria are not directly toxic but oysters with high coliform concentrations cannot be directly harvested for food. Applequist *et al.* (1972) also found the harbor to be enriched in mercury which they attributed to municipal sewage outfalls.

In summary, all combined analyses for both oyster mortality and growth indicated that significant variation occurred between years but not between experimental stations. The one parameter, dry weight condition index, which did represent a difference between experimental stations, was a consistent pre-and post-operational phenomenon. The interpretation of these results leads to the conclusion that no effect of the operation of New Haven Harbor Station could be determined on the growth, mortality or commercial viability (as measured by condition index) of experimental oyster populations within New Haven Harbor.

LITERATURE CITED

- Army Corps of Engineers. 1973. Final environmental statement, maintenance dredging, New Haven Harbor. New England Division, Waltham, MA.
- Butler, P. A. 1949. An investigation of oyster producing areas in Louisiana and Mississippi damaged by flood waters in 1945. Special Scientific Report, U.S. Fish and Wildl. Serv., No. 8. 29 pp.
- Conover, W. J. 1971. Practical non-parametric statistics. J. Wiley & Sons, New York. 462 pp.
- Dame, R. F., Jr. 1971. The ecological energies of growth, respiration and assimilation in the intertidal American oyster, *Crassostrea virginica* (Gmelin). Ph.D. dissertation, University of South Carolina, Columbia. 81 pp.
- Davis, H. C. and A. Calabrese. 1964. Combined effects of temperature and salinity on development of eggs and growth of larvae of *M. mercenaria* and *C. virginica*. Fish. Bull. 63:643-655.
- Diaz, R. J. 1968. Effects of thermal shock on larvae of the oyster, *Crassostrea virginica* (Gmelin). Master's thesis, Virginia Institute of Marine Science, Gloucester Point. 35 pp.
- Frazier, J. M. 1975. The dynamics of metals in the American oyster, *Crassostrea virginica*. I: Seasonal effects. Chesapeake Science. 16(3):162-171.
- Galtsoff, P. S. 1964. The American oyster, *Crassostrea virginica* (Gmelin). U.S. Fish and Wildlife Service, Fishery Bulletin. 64:1-480.
- Gill, J. L. 1977. Multiple comparisons of means when variance is not homogeneous. Jour. of Dairy Science. 60:444-449.
- Grave, C. (ed.). 1912. A manual of oyster culture in Maryland. Fourth Report of the Shell Fish Commission of Maryland, 1912. pp. 279-348.
- Hopkins, A. E. 1949. Determination of condition of oysters. Science. 110:567-588.
- Kirk, R. E. 1968. Experimental design. Procedures for the Behavioral Sciences. Brooks/Cole Publ. Company, Belmont, California. 577 pp.
- Loosanoff, V. L. 1932. Observations on propagation of oysters in James and Corrotonan Rivers and seaside of Virginia. Publication of the Virginia Commission of Fisheries. 1-46.

- _____. 1965. Gonad development and discharge of spawn in oysters of Long Island Sound. Biol. Bull. 129:546-561.
- _____. 1966. Time and intensity of setting of the oyster, *Crassostrea virginica*, in Long Island Sound. Biol. Bull. 130:211-227.
- Lough, R. G. 1975. A reevaluation of the combined effects of temperature and salinity on survival and growth of bivalve larvae using response surface techniques. Fish. Bull. 73(1):86-89.
- MacKenzie, C. L. 1970a. Oysters culture in Long Island Sound. U.S. Fish and Wildlife Service, Separate No. 859. 27-40
- _____. 1970b. Causes of oyster spat mortality, conditions of oyster setting beds and recommendations for oyster bed management. Proceedings of the National Shell Fisheries Association. 60:59-67.
- _____. 1977a. Use of quicklime to increase oyster seed production. Agriculture. 10(1977):45-51.
- _____. 1977b. Development of an aquacultural program for rehabilitation of damaged oyster reefs in Mississippi. Marine Fisheries Review. 39(5):1-13.
- Normandeau Associates, Inc. 1973. New Haven Harbor Ecological Studies, New Haven, Connecticut. Annual Report 1971-1972 for The United Illuminating Company. 208 pp.
- _____. 1974a. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report, 1972-1973 for The United Illuminating Company, New Haven, Connecticut. 215 pp.
- _____. 1974b. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Interim Report, May-December 1973 for The United Illuminating Company, New Haven, Connecticut. 199 pp.
- _____. 1975a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report, 1974 for The United Illuminating Company, New Haven, Connecticut. 223 pp.
- _____. 1976. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report, 1975 for The United Illuminating Company, New Haven, Connecticut. 312 pp.
- _____. 1977. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report, 1976 for The United Illuminating Company, New Haven, Connecticut. 376 pp.
- _____. 1978. New Haven Harbor Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report, 1977 for The United Illuminating Company, New Haven, Connecticut. 359 pp.

Ogle, J., S. M. Ray and W. J. Wardle. 1977. The effect of depth on survival and growth of oysters in suspension culture from a petroleum platform off the Texas Coast. Gulf Research Reports. 6(1): 31-37.

Sakuda, H. M. 1966. Condition of American oyster *Crassostrea virginica*, in West Lock, Pearl Harbor, Hawaii. Transactions of the American Fisheries Society. 95(4):426-429.

Scheffe, H. 1969. Analysis of Variance. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 199 pp.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry, the principles and practice of statistics in biological research. W. H. Freeman and Company, San Francisco. 776 pp.

STATISTICAL APPENDIX

APPENDIX

The purpose of this statistical appendix is to clarify the basic assumptions and constraints relevant to the tests of specific hypotheses carried out on the data. The 3-way G test used to evaluate hypothesis (1) had no constraints other than those already described in the Methods Section.

The statistical analysis used to test hypothesis (2) contained some bias. The assumptions underlying a covariance analysis include the usual ones of normality and homogeneity of variance as well as additional assumptions concerning the linearity of dependent and concomitant variables. The very important assumption of homoscedasticity (homogeneity of variance) was not met by the data set even after the application of various transformations. Differences in variances were severe between years and less severe but usually significant between stations in the same year. There is a strong possibility that oysters each year were not sampled from the same population, i.e., the stocks from which the experimental oysters were acquired each year had sufficiently different genomes that the environmental conditions to which they were exposed resulted in different phenotypic expressions of the parameters measured.

The covariance analysis adjusts differences among treatments for the effects of the covariate. In this analysis differences in final length due to differences in initial length were removed so that only variation due to station, year and "error" were assessed. The Scheffe method is generally used to test contrasts among means in a covariance analysis. This is a very conservative technique when used in pairwise comparisons and when data are heterogeneous the procedure maintains an "average" alpha level over the series of all possible linear comparisons. The Scheffe method for pairwise comparisons was employed in this analysis. A completely unbiased parametric test for this hypothesis is not currently available.

Hypothesis (3), length changes at the two experimental stations occur in the same time periods for a given year, was tested using a Geisser-Greenhouse conservative F-test (Kirk, 1968) for fixed-effects in a mixed-model, randomized-block design with repeated measures ANOVA. Such a design requires the stringent assumption of symmetry of the variance-covariance matrix; however, with the conservative procedure used there is no need to test for or meet this requirement if treatment effects are significant.

Treatment effects were highly significant for all data (Appendix Table 9-1) indicating that increase in length (growth) was significant at both stations in 1975, 1976 and 1977.

Tukey procedures for pairwise multiple comparisons were then employed to determine those months between which mean length differed significantly. Of particular interest are significant differences between adjacent months as these indicate periods of active growth. Except for Harbor Station, 1977, variances by months were homogeneous within each station/year data set, therefore modified comparison procedures had to be used for the Harbor Station, 1977 data in order to maintain an experimentwise alpha level of 0.05 (Gill, 1977). Appendix Tables 9-2 and 9-3 show the results of this analysis which are summarized in Table 9-8 and Figure 9-7.

VARIABLE	SOURCE OF VARIATION	SS	DF	MS	F _{conv.}	DF _{cons.}	F _{cons.}
Harbor Station, 1975	Months	6,428.3	5	1,285.67	63.396***	7,45	63.396***
	Oysters	59,396.3	45	1,319.92	65.085***		
	Months x Oysters	4,562.3	225	20.28			
	Total	70,387.0	275				
Harbor Station, 1976	Months	24,117.5	6	4,019.58	220.61***	1,59	220.61***
	Oysters	12,998.5	59	220.31	12.09***		
	Months x Oysters	6,449.9	354	18.22			
	Total	43,566.0	419				
Harbor Station, 1977	Months	19,929.2	6	3,321.53	234.24***	1,59	234.24***
	Oysters	7,981.8	59	135.29	9.54***		
	Months x Oysters	5,019.1	354	14.18			
	Total	32,930.1	419				
Fort Hale, 1975	Months	8,155.18	6	1,631.04	74.716***	1,48	74.716***
	Oysters	66,201.32	48	1,379.19	63.178***		
	Months x Oysters	5,240.15	240	21.83			
	Total	79,596.65	293				
Fort Hale, 1976	Months	22,124.5	6	3,687.41	199.32***	1,56	199.32***
	Oysters	20,758.0	56	370.68	20.04***		
	Months x Oysters	6,215.2	336	18.50			
	Total	49,097.7	398				
Fort Hale, 1977	Months	5,582.2	6	930.37	109.20***	1,23	109.20***
	Oysters	2,367.5	23	102.93	12.81***		
	Months x Oysters	1,176.1	138	8.52			
	Total	9,175.8	117				

SS = Sum of squares
 DF = degrees of freedom
 MS = mean square

F_{conv} = conventional F ratio
 DF_{cons} = conservative degrees of freedom
 F_{cons} = conservative F ratio

APPENDIX TABLE 9-2. TUKEY'S PROCEDURE. MEAN LENGTH (MM) BY MONTH -- FORT HALE.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

FORT HALE 1975

	NOV	OCT	SEP	AUG	JUL	JUN
106.18 Nov			*	*	*	*
106.02 Oct				*	*	*
103.35 Sep				*	*	*
98.78 Aug					*	*
95.12 Jul						
92.51 Jun						

$$\hat{L} \geq \text{MSe}/n \quad q_{.05;6;293}$$

$$\geq 21.83/49$$

$$\geq 2.7079$$

FORT HALE 1976

	OCT	NOV	SEP	AUG	JUL	JUN	MAY
103.40 Oct		*	*	*	*	*	*
100.00 Nov				*	*	*	*
98.68 Sep				*	*	*	*
95.93 Aug					*	*	*
91.49 Jul						*	*
85.67 Jun							*
81.25 May							

$$\hat{L} \geq 18.50/57 \quad (4.1954) = 2.3901$$

FORT HALE 1977

	NOV	SEP	OCT	AUG	JUL	MAY	JUN
84.67 Nov				*	*	*	*
83.77 Sep				*	*	*	*
83.00 Oct				*	*	*	*
77.58 Aug					*	*	*
72.63 Jul							
70.63 May							
70.58 Jun							

$$\hat{L} \geq 8.52/24 \quad (4.2317) = 2.5213$$

APPENDIX TABLE 9-3. TUKEY'S PROCEDURE. MEAN LENGTH (MM) BY MONTH -- HARBOR STATION.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

HARBOR STATION, 1975

	NOV	SEP	OCT	AUG	JUL	JUN
100.65 Nov				*	*	*
100.30 Sep				*	*	*
99.20 Oct				*	*	*
95.26 Aug						*
94.91 Jul						*
86.63 Jun						

$$\hat{L} > \frac{MSe}{n} \quad q_{.05; K; Va} = 2028/45 \quad (4.0652) = 26992$$

HARBOR STATION, 1976

	OCT	NOV	SEP	AUG	JUL	JUN	MAY
104.45 Oct			*	*	*	*	*
102.93 Nov			*	*	*	*	*
98.40 Sep				*	*	*	*
95.52 Aug					*	*	*
92.18 Jul						*	*
86.12 Jun							*
82.67 May							

$$\hat{L} > 18.22/60 \quad (4.1941) = 2.31118$$

HARBOR STATION, 1977 (Modified Tukey Procedures for Heterogeneous Variance)

	OCT	NOV	SEP	AUG	JUL	JUN	MAY
88.35 Oct				*	*	*	*
87.28 Nov				*	*	*	*
85.85 Sep				*	*	*	*
78.97 Aug					*	*	*
73.77 Jul							
72.02 Jun							
71.47 May							

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

10.0 TRACE METALS

by K. K. Turekian

Department of Geology and Geophysics
Yale University, New Haven, Connecticut

TABLE OF CONTENTS

	PAGE
<i>INTRODUCTION.</i>	10-1
<i>TRACE METALS IN SEDIMENTS</i>	10-2
<i>Controls on Trace-Metal Distribution in Sediments</i>	10-2
<i>The Distribution of Trace Metals in Long Island Sound Sediments</i>	10-9
<i>The Role of Atmospheric Transport in Trace Metal Input to Long Island Sound.</i>	10-15
<i>The Kinetics of Trace-Metal Scavenging from the Water Column</i>	10-20
<i>Summary of Controls on Trace Metal Distribution in Long Island Sound Sediments.</i>	10-23
<i>TRACE METALS IN ORGANISMS</i>	10-24
<i>Observed Trace Metal Distributions in Mussels and Oysters from Long Island Sound.</i>	10-24
<i>Mussels</i>	10-26
<i>Time Variations in <u>Mercenaria</u> and <u>Crassostrea</u> from New Haven Harbor</i>	10-33
<i>Trace-Metals Composition of Organisms in the Central Basin of Long Island Sound.</i>	10-36
<i>ANALYSIS OF IMPACTS</i>	10-40
<i>SUMMARY AND CONCLUSIONS</i>	10-41
<i>Long Island Sound</i>	10-41
<i>New Haven Harbor.</i>	10-41
<i>REFERENCES CITED.</i>	10-43

LIST OF FIGURES

	PAGE
10-1. The concentration of silver in the Quinnipiac River system.	10-4
10-2. The concentration of silver, lead and copper in sediments of the Quinnipiac River system and in New Haven Harbor.	10-5
10-3. The distribution of mercury (in ppm) in the tops of sediments from New Haven Harbor.	10-7
10-4. The relation of zinc concentration to organic content in sediments from the New Haven Harbor channel and potential dredge disposal site in Long Island Sound . .	10-8
10-5. Distribution of copper in the tops of cores raised from Long Island Sound	10-10
10-6. Distribution of zinc in the tops of cores raised from Long Island Sound.	10-11
10-7. Distribution of lead in the tops of cores raised from Long Island Sound.	10-12
10-8. Sediment size distribution in Long Island Sound	10-13
10-9. The depth of distribution of Hg, Pb, Cu and Zn in cores	10-14
10-10. Correspondence of age of layers in the Farm River salt marsh, determined by Pb-210 and sea level rise curve from tide gauge data.	10-16
10-11. Flux of metals as a function of time in the Farm River salt marsh.	10-18
10-12. Total ²¹⁰ Pb in surface water versus concentration of suspended solids taken over time at a station in central Long Island Sound	10-21
10-13. Copper concentration in oysters as a function of time at six locations along the Connecticut coast.	10-21
10-14. Cadmium concentration in oysters as a function of time at six locations along the Connecticut coast.	10-27
10-15. Zinc concentration in oysters as a function of time at six locations along the Connecticut coast.	10-27

10-16.	Sampling locations for mussels studied for trace metals.	10-28
10-17.	Lead concentration of dry soft tissues of mussels as a function of location along the Connecticut coast. . .	10-28
10-18.	Cadmium concentration of dry soft tissues of mussels as a function of location along the Connecticut coast .	10-29
10-19.	Copper concentration of dry soft tissues of mussels as a function of location along the Connecticut coast .	10-29
10-20.	Zinc concentration of dry soft tissues of mussels as a function of location along the Connecticut coast .	10-30
10-21.	Nickel concentration of dry soft tissues of mussels as a function of location along the Connecticut coast .	10-30
10-22.	Distribution of Nickel in unfiltered surface waters of Long Island Sound.	10-32

LIST OF TABLES

	PAGE
10-1. CALCULATED EXCESS METAL FLUX ($\mu\text{g}/\text{cm}^2/\text{yr}$) TO THE SURFACE OF THE FARM RIVER SALT MARSH COMPARED TO MEASURED ATMOSPHERIC DEPOSITION RATES AT SELECTED SITES.	10-19
10-2. ROLE OF PLANKTON IN ^{210}Pb TRANSPORT OUT OF THE OCEAN SURFACE LAYER.	10-22
10-3. ^{210}Pb AND PLUTONIUM INVENTORIES IN LONG ISLAND SOUND SEDIMENTS.	10-25
10-4. TIME VARIATION IN CONCENTRATIONS OF Cu, Pb, Zn, Cd, AND Hg IN SOFT TISSUE OF <i>MERCENARIA MERCENARIA</i> AT TWO SITES IN NEW HAVEN HARBOR.	10-34
10-5. COPPER AND ZINC CONCENTRATIONS ($\mu\text{g}/\text{g}$ OF DRY SOFT TISSUE) OF DIFFERENT BIVALVE SPECIES AT VARIOUS LOCATIONS IN NEW HAVEN HARBOR.	10-35
10-6. TRACE ELEMENTS IN SMALL SEDIMENT-DWELLING CLAMS IN NEW HAVEN HARBOR AND CENTRAL LONG ISLAND SOUND	10-37
10-7. COMPOSITION OF ANEMONES FROM LONG ISLAND SOUND AND THE MID-ATLANTIC RIDGE	10-39

10.0 TRACE METALS

By K. K. Turekian
Department of Geology and Geophysics
Yale University, New Haven, Connecticut

INTRODUCTION

The mobilization of many trace elements is effected by natural processes acting at the Earth's surface. Weathering results in the alteration of rocks with the release and redistribution of many of the trace elements in the process. Some part of this released load enters the groundwater system in solution and ultimately makes its way to the oceans via streams. Another part becomes incorporated in the soil profile in association with the organic fraction. This material also makes its way to the sea as the result of erosion. During transport the different components of this entourage are influenced by the chemical-physical processes acting in streams and in the estuarine system resulting in the distribution of the trace metals that we observe in the estuary. Upon reaching the estuarine zone the metals do not commonly become passive but can undergo a flux and redistribution through natural sedimentation-erosion processes, chemical mobilization, or incorporation into biota.

Man has added to the natural trace-metal load by injecting materials, resulting from his activities, into every part of the pathway. Atmospheric transport deposits alien nuclides on to the surface invading the soil profiles as well as the estuarine or sea surface. Metal-bearing effluent from industries imprints the streams and groundwater with contaminants. Domestic sewage is funneled through treatment plants, but not all metals or other toxic materials are completely isolated.

The consequences of these human perturbations on the natural trace-metal regime of the coastal system are readily observed in the biota, water and sediments. Elevated metal levels have been well documented. The response, however, has not been the same everywhere and the potential damage to the environment cannot always be directly correlated

with increased contaminant levels even where they occur. The tolerable levels, the degrees of irreversible sequestering and other factors all must enter into the evaluation of man's impact on the environment.

In this report I discuss what we now know of the factors influencing controls on trace-metal distribution in New Haven Harbor and Long Island Sound and the subsequent effects on resident biota. Consideration is also given to possible effects of New Haven Harbor Station on harbor trace-metal concentrations. I draw on the published and unpublished work of our group at Yale, as well as the results of several other studies done at other institutions.

TRACE METALS IN SEDIMENTS

Controls on Trace-Metal Distribution in Sediments

Stream Supply

The dissolved trace-metal concentration of streams is controlled not only by input from the weathering of rocks and from aerosols but also by the chemical reactions occurring within the streams. The evidence from studies utilizing ^{210}Pb as a tracer for heavy metal behavior in streams indicates rapid scavenging by particles associated with the flowing water (Benninger, Lewis and Turekian, 1975; Lewis, 1977). Surfaces of organic debris and manganese and iron oxide coatings appear to be the primary agents. Competing with this process is the formation of dissolved organic-chelated compounds. Much of the dissolved iron found in streams, for instance, is in this form (Sholkovitz, 1976).

A study of Connecticut streams (Turekian, 1971) indicated that the trace-metals, cobalt and silver, are maintained in solution at low concentrations as the result of the scavenging action of suspended particles. Even where acid industrial wastes are dumped into the stream, as in the Naugatuck River which joins the Housatonic River, suspended particles act to lower the dissolved concentrations. I infer from studies involving the behavior of ^{210}Pb in the Susquehanna River and of

Co and Ag in the major Connecticut rivers that the dissolved trace-metal concentration is maintained at low levels in stream water and thus the primary mode of transportation to the estuarine zone is via particles.

Our work on the Quinnipiac River, a river carrying effluents from the major metal industries of Meriden and Wallingford and entering into New Haven Harbor, supports this expectation. Figure 10-1 shows the distribution of total silver in Quinnipiac River waters and demonstrates an increase in concentration through Wallingford. In Wallingford, the $>0.45\mu\text{m}$ fraction (associated with particles) adds to the $3\text{ }\mu\text{g/l}$ delivered from the uncontaminated reservoirs.

Figure 10-2 shows that the bottom sediments of the system are strongly impacted by the trace-metal injections from industry. The remarkable feature of the observed pattern, however, is that the concentrations of Ag, Pb and Cu decrease almost to ambient precontaminated sediment values shortly after the point of impact. This is probably due to the presence of a series of small dams along the Quinnipiac River that allow the metal-laden particles to settle out.

The Housatonic River, emptying into the Sound about 15 km to the west of New Haven Harbor, with its heavily polluted tributary, the Naugatuck River, as mentioned above, supplies a significant amount of trace metals to the adjacent part of the Long Island Sound, mainly in particle form (Turekian, 1971). In contrast, as noted above, the Quinnipiac River, although also polluted by metals, appears to be retaining the metal-contaminated sediments behind a series of dams. The stream transport of trace metals to New Haven Harbor and on to the Sound is minimal compared to sources in the harbor itself as we shall see. The role of damming is certainly one important factor in inhibiting transfer of metal-polluted sediments to the estuarine zone.

Sewer Outfalls - New Haven Harbor

Appelquist, Katz and Turekian (1972) showed that the mercury concentration in the sediments of New Haven Harbor varied in relation to

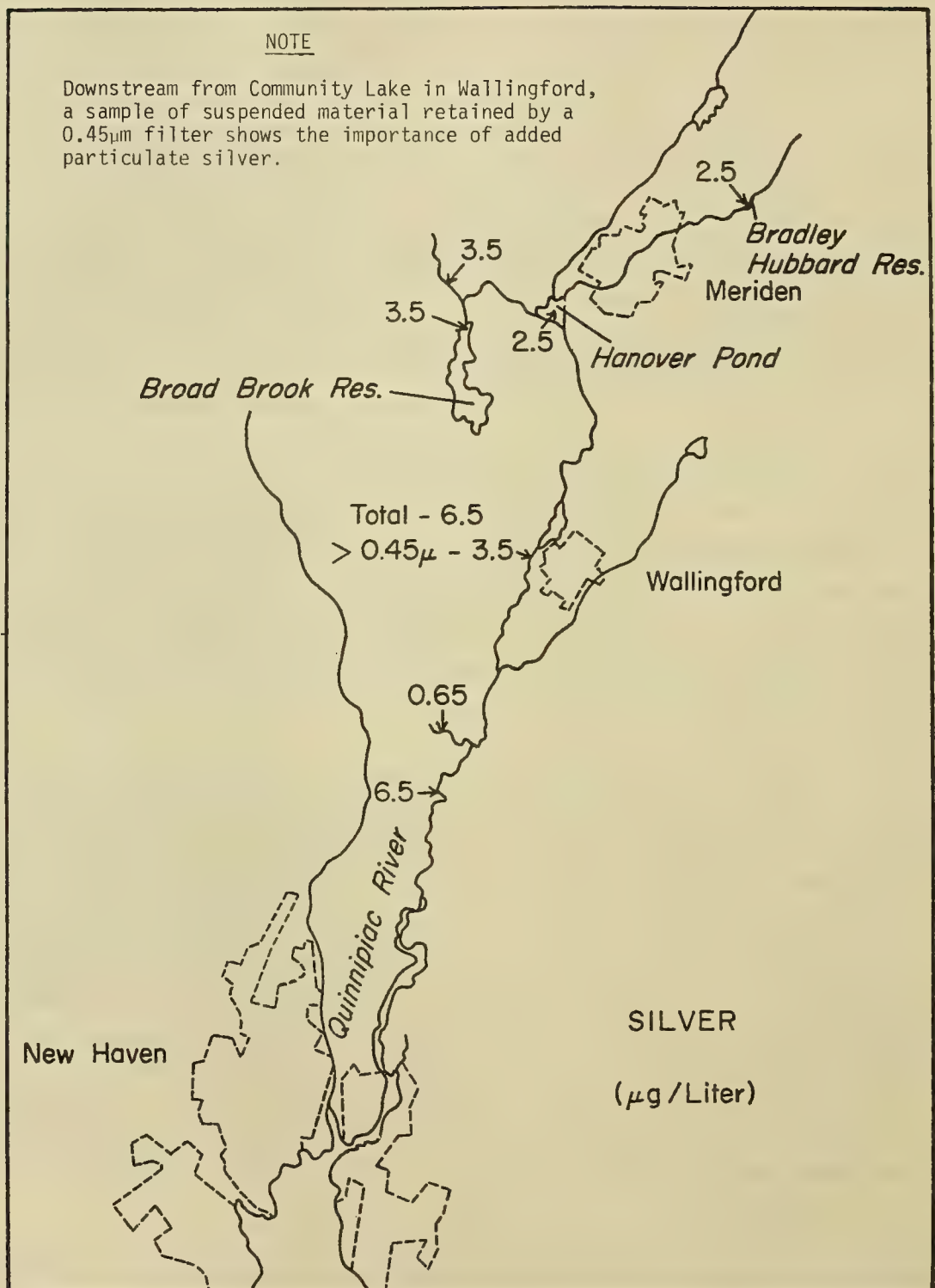


Figure 10-1. The concentration of silver in the Quinnipiac River system. Analyses are on unfiltered water. New Haven Harbor Ecological Studies Summary Report, 1979.

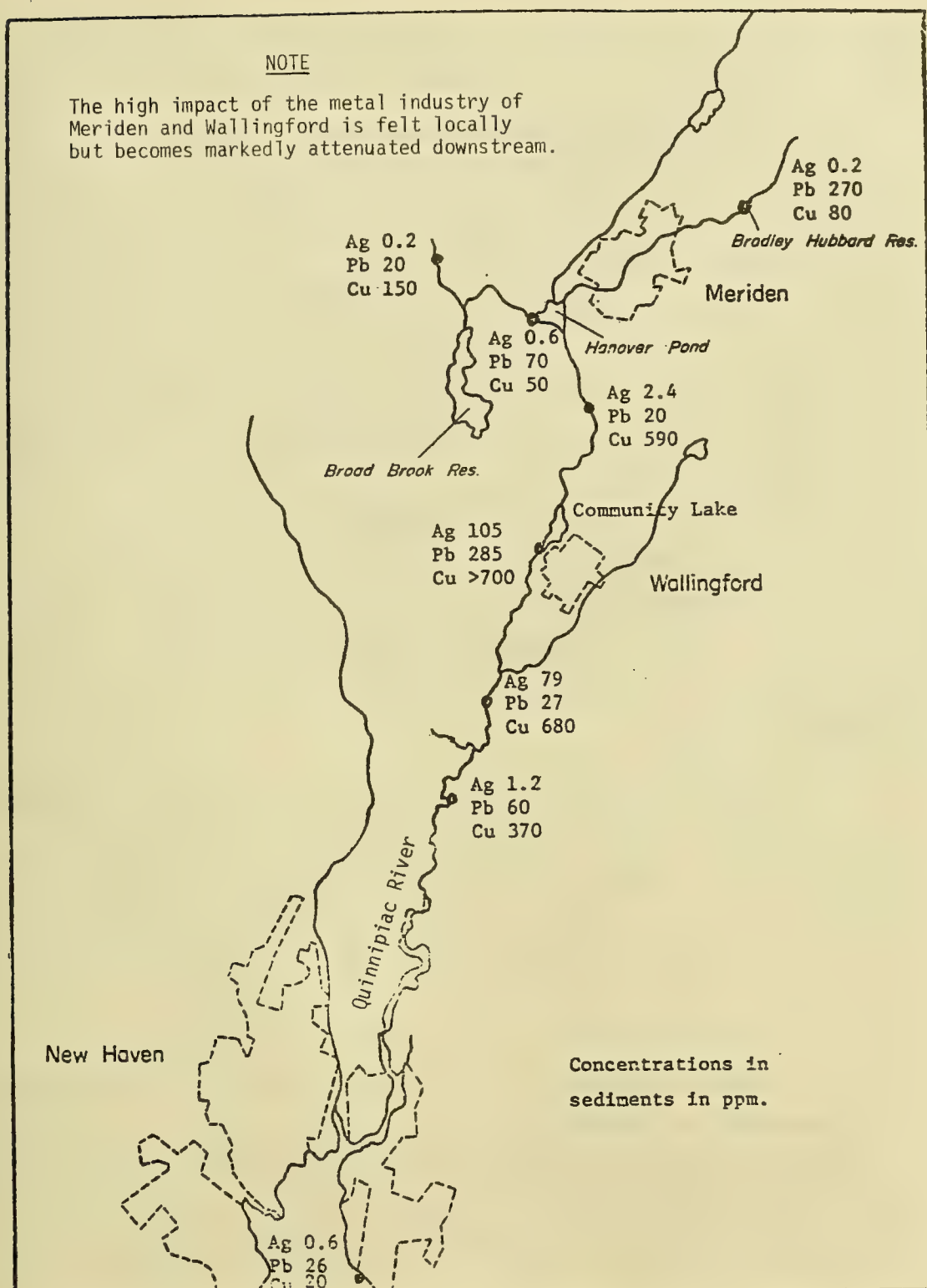


Figure 10-2. The concentration of silver, lead and copper in sediments of the Quinnipiac River system and in New Haven Harbor. New Haven Harbor Ecological Studies Summary Report, 1979.

distance from the several sewage treatment plants discharging into the harbor (Figure 10-3). As is the case with most of the older New England cities, storm sewers are combined with sanitary sewers and the effluent is processed through the sewage treatment plants. During periods of high discharge associated with large storms, the treatment plant is bypassed and the unprocessed effluent is debouched directly into the harbor, resulting in organic carbon and metal enrichment of the sediment around the outfalls. We found high Pb, Zn and Cu associated with the sewer outfall south of Long Wharf. Our most detailed study of the sedimentary organic and heavy metal content association with sewer outfalls was made prior to construction of New Haven Harbor Station on the East Shore just off the Harbor Station property (old Coke Works site). Detailed studies of the tissue heavy metals concentration of bivalves from the same area will be discussed later. A plot of the zinc concentration versus volatile solids (assumed to be mainly organic material) for New Haven Harbor is shown in Figure 10-4. Comparison with a site in central Long Island Sound graphically shows the role of near-shore outfall contamination.

Thus we see that the trace-metal patterns in near-shore sediments of the Connecticut shore of Long Island Sound are determined primarily by the location of sewer outfalls. The stream supply of industrial contamination is expressed where damming does not act as a sediment trap between the point of injection and the entry into the estuary.

Maintenance or construction-related dredging of metal-contaminated sediments results in the transport of the material to other locations in the Sound where the dredge spoil is dumped. The identification of such dumping has been made in the New York Bight using trace metals and organic content as well as other indicators (Gross, 1976; Carmody, Pearce and Yasso, 1973) but, as we shall see, other factors operate in Long Island Sound to attenuate the effect of maintaining a local identity.

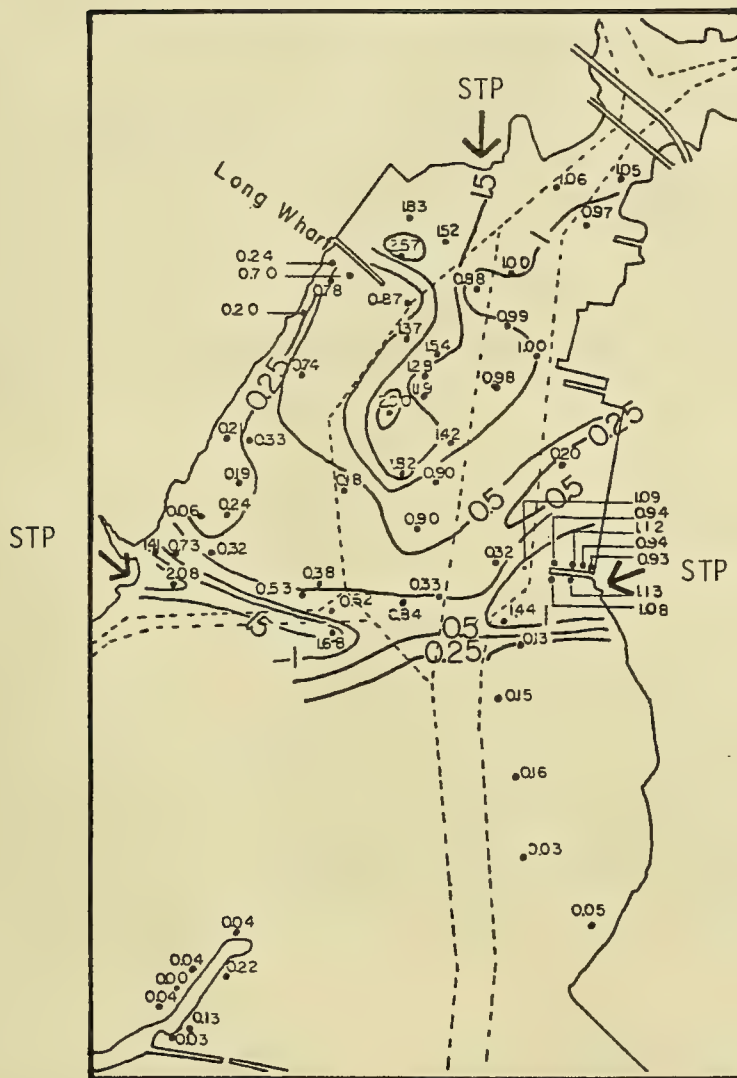


Figure 10-3. The distribution of mercury (in ppm) in the tops of sediments from New Haven Harbor. The dominant control is in proximity to sewage treatment plant (STP) outfalls (after Applequist, Katz and Turekian, 1972). New Haven Harbor Ecological Studies Summary Report, 1979.

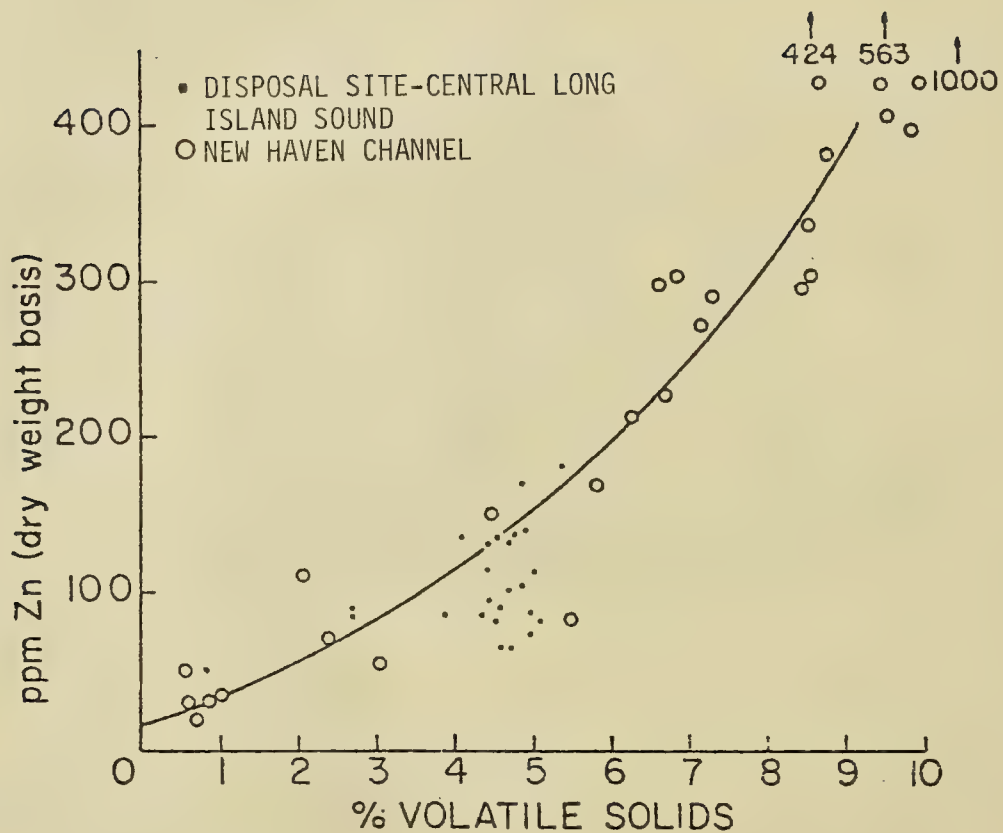


Figure 10-4. The relation of zinc concentration to organic content (expressed as % volatile solids) in sediments from the New Haven Harbor channel and potential dredge disposal site in Long Island Sound about 5 miles south of New Haven. Data from the U.S. Corps of Engineers files (New Haven Harbor Project: Report on Environmental Sampling and Testing, 1972). These show concordance with Yale data on trace elements obtained throughout the harbor. New Haven Harbor Ecological Studies Summary Report, 1979.

The Distribution of Trace Metals in Long Island Sound Sediments

Horizontal Distribution

Greig, Reid and Wenzlogg (1977) have recently made a detailed study of the distribution of a number of trace metals (Sb, Cd, Co, Cr, Cu, Pb, Mn, Ni, Ag, Sc, Zn) in the top 4 cm of Long Island Sound sediments using a Smith-McIntyre grab sampler. The choice of 4 cm was fortuitous since this represents, within plus or minus a centimeter, the rapidly reworked portion of the sediments as determined at Yale University using ^{234}Th (Aller and Cochran, 1976). Figures 10-5 through 10-7 show concentration maps for Cu, Zn and Pb constructed from their data.

The primary control on the trace-metal concentration is the grain size of the sediment. This can be seen by comparing Figures 10-5 through 10-7 with Figure 10-8 which shows the grain-size distribution in the Sound. The sand rich sediments have the lowest trace-metal content. There is, however, an important second-order effect related to the source of trace metals to coastal waters. Sediments adjacent to Throgs Neck, the Housatonic River and New Haven Harbor are higher in trace metals than other sediments of the same grain size. These three areas are heavily impacted either by sewer outfalls or direct injection of industrial sewage along a contiguous channel (as in the Naugatuck-Housatonic system).

Distribution With Depth of Trace Metals in Cores

A number of cores collected from central Long Island Sound have been analyzed for trace metals as a function of sediment depth (Thomson, Turekian and McCaffrey, 1975). They show roughly the same patterns for Cu, Zn, Pb and Hg (Figure 10-9) with a homogeneous upper 2 to 4 cm zone and a roughly exponential decrease to a depth of about 30 cm. At greater depths there are occasional peaks of high concentrations.

Thomson, Turekian and McCaffrey (1975) interpreted the distribution patterns of metals to 30 cm as representing a superficial zone

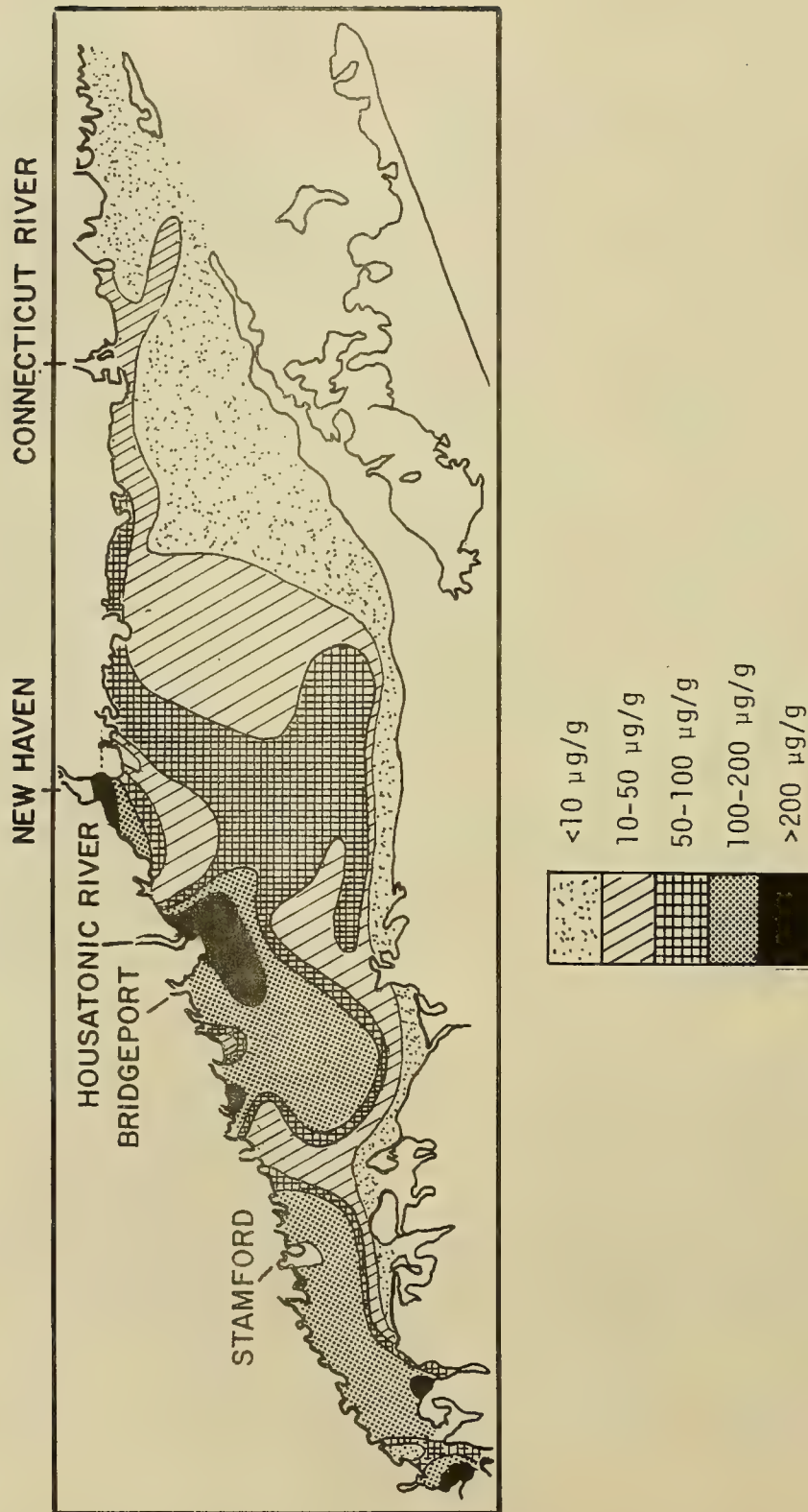


Figure 10-5. Distribution of copper in the tops of cores raised from Long Island Sound. Map constructed from the data of Greig, Reid and Weazloff (1977). New Haven Harbor Ecological Studies Summary Report, 1979.

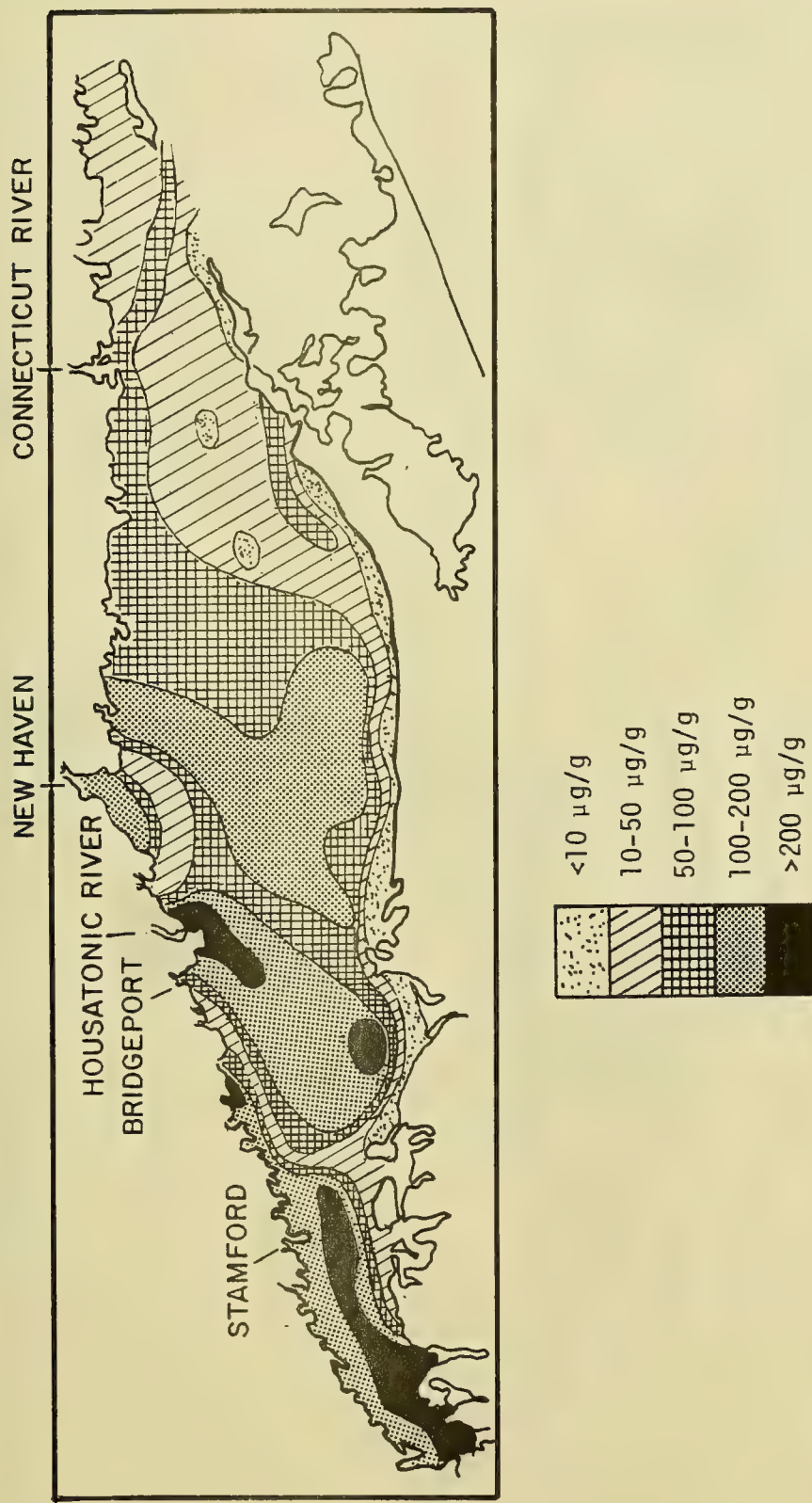


Figure 10-6. Distribution of zinc in the tops of cores raised from Long Island Sound. Map constructed from the data of Greig, Reid and Weazloff (1977). New Haven Harbor Ecological Studies Summary Report, 1979.

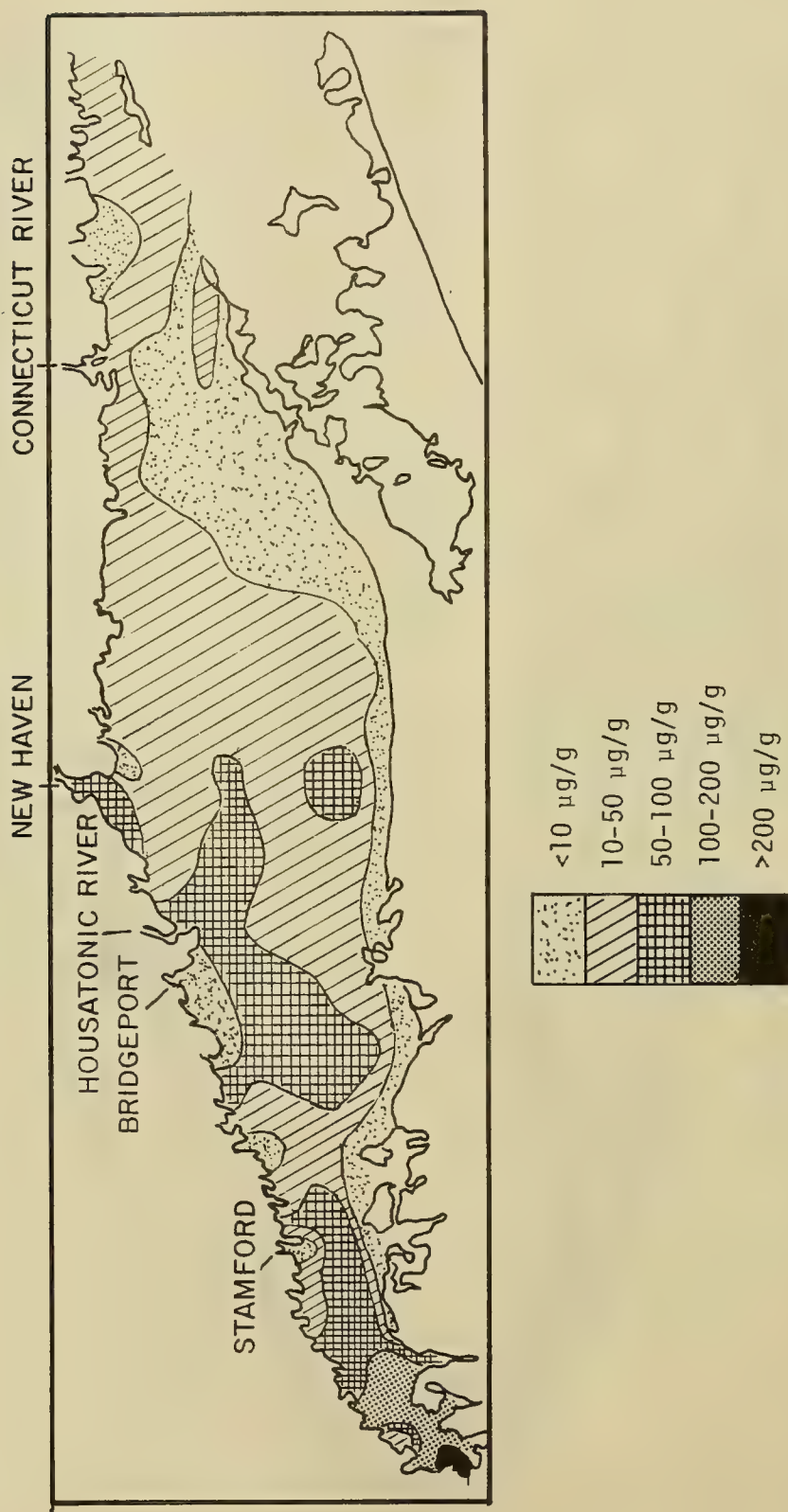


Figure 10-7. Distribution of lead in the tops of cores raised from Long Island Sound. Map constructed from the data of Greig, Reid and Weazloff (1977). New Haven Harbor Ecological Studies Summary Report, 1979.

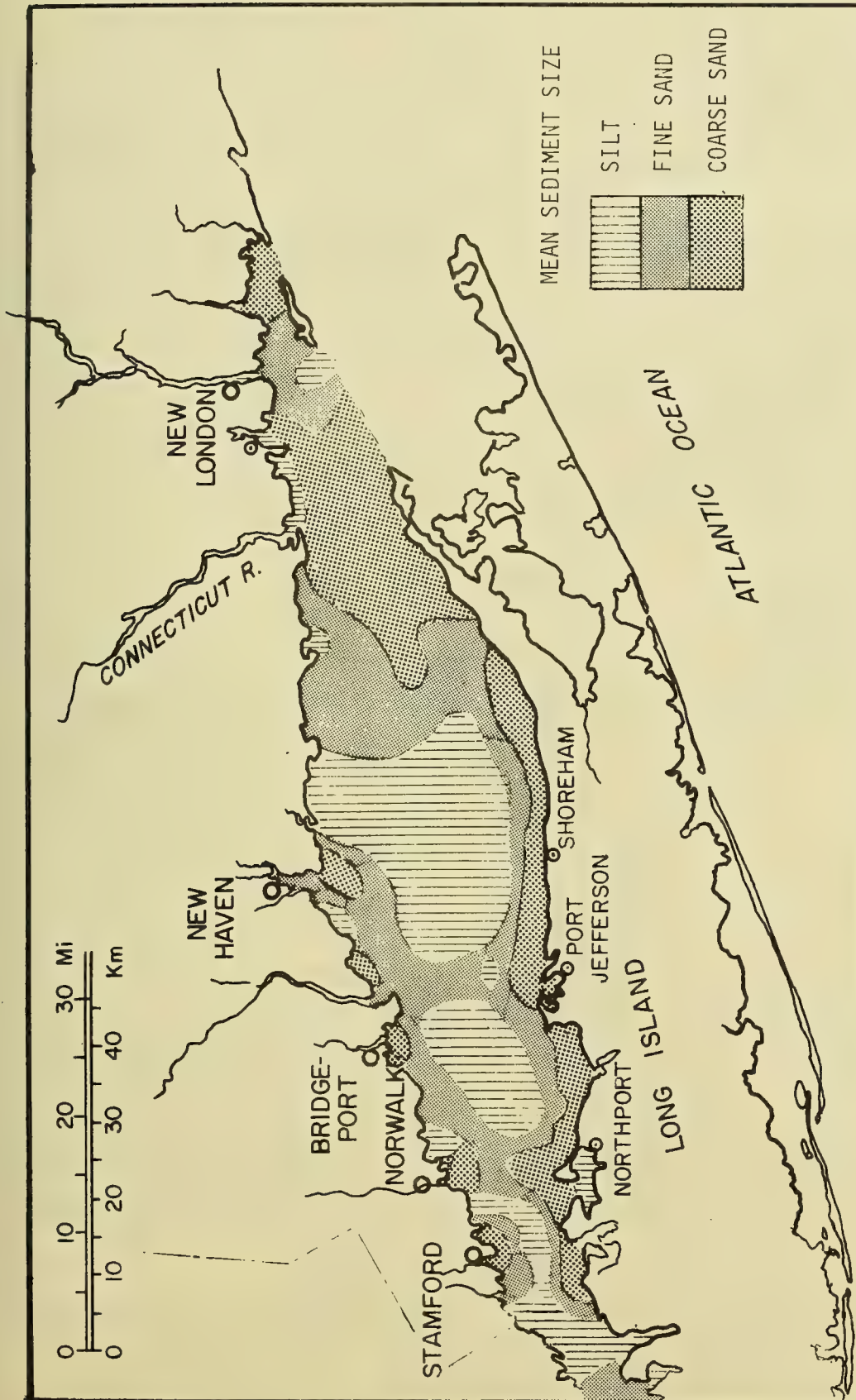


Figure 10-8. Sediment size distribution in Long Island Sound. (From "Long Island Sound: An Atlas of Natural Resources" published by the Connecticut Department of Environmental Protection in 1977). New Haven Harbor Ecological Studies Summary Report, 1979.

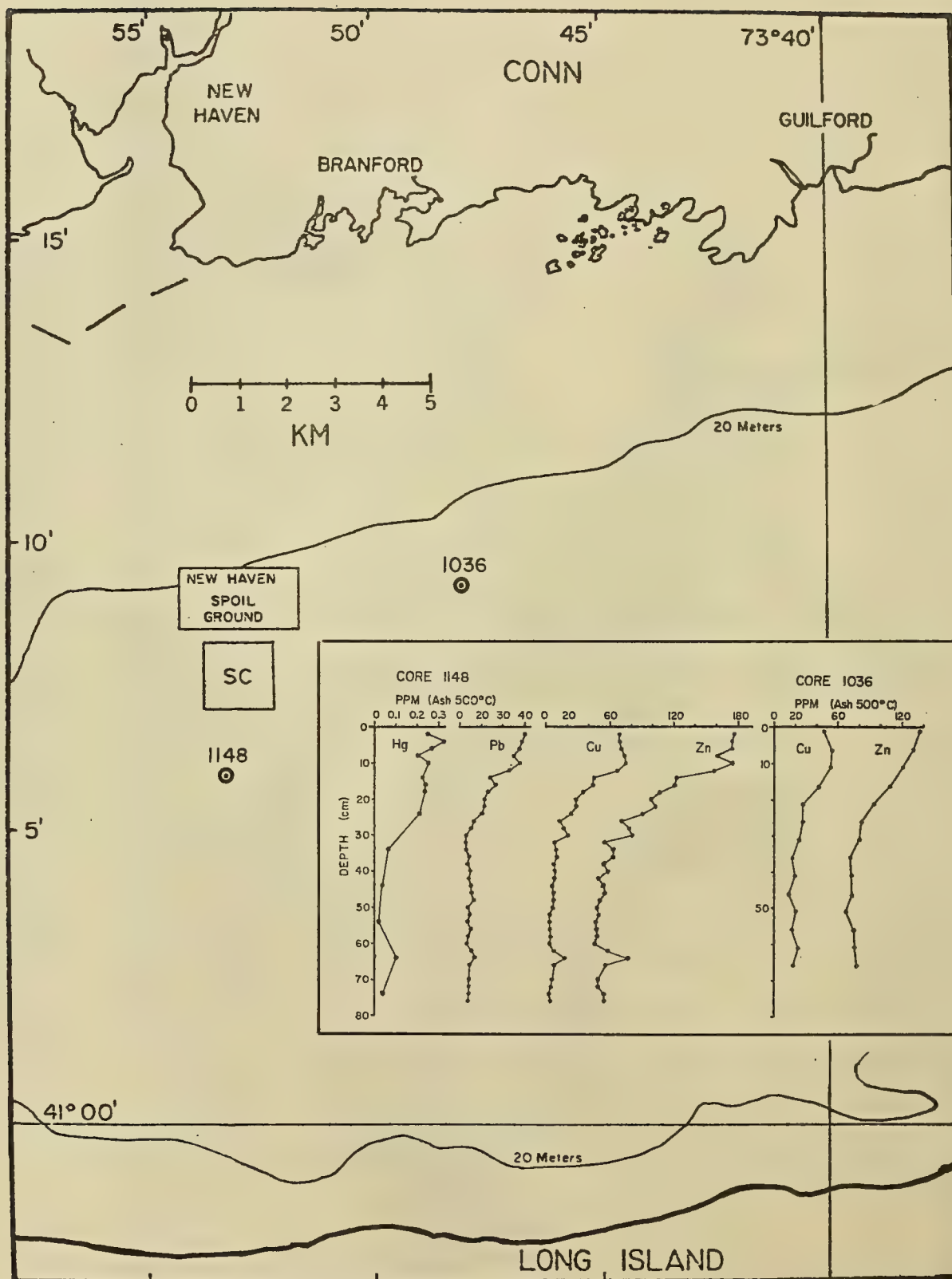


Figure 10-9. The depth of distribution of Hg, Pb, Cu and Zn in cores: 1148 (from Thomson, Turekian and McAffrey, 1975) and 1036 (analyzed at Yale); showing their respective locations off New Haven Harbor. New Haven Harbor Ecological Studies Summary Report, 1979.

of biologically mixed material and the deeper portion as reflecting the increasing contamination of Long Island Sound sediments by human introduction of metals. Assuming no mixing below the top few centimeters, they used the distribution of ^{210}Pb to date the core and put a chronology on the metal profiles.

We now know that this was an oversimplified interpretation. Benninger et al (1979) have shown that the trace-metal and ^{210}Pb data can be interpreted as due to diffusion-like biological mixing to depths of 15 cm and episodic deep burrowing to depths of one meter or more. Thus the exponential decrease of trace metals is the result of two processes, one an increasing metal flux to the sediments with time, and the other a redistribution based on a diffusion-like mixing process near the top of the core. It is not possible to reconstruct the time-scale of metal pollution accumulations without unravelling the contributions of the sediment mixing processes.

The Role of Atmospheric Transport in Trace Metal Input to Long Island Sound

The Historical Record in a Salt Marsh

Unlike sediments in Long Island Sound, salt marsh deposits are not subject to major bioturbation. Therefore, if they continue to grow upward, each layer should preserve a record reflective of the depositional environment at that point in time. As sea level rises over geologic time the saltmarsh elevation will grow upward to keep pace. Tidal gauge data (Figure 10-10) show that during the past 100 years sea level has been rising relative to the Connecticut coast at a rate of about 2 mm per year. This is probably related to a world-wide rise in sea level resulting from climate-induced changes on the earth's water balance.

McCaffrey (1977) and McCaffrey and Thomson (1979) have shown that the ^{210}Pb (22 year half life) concentration at each level in a vertical profile of the salt marsh predicts the rate of sea level change

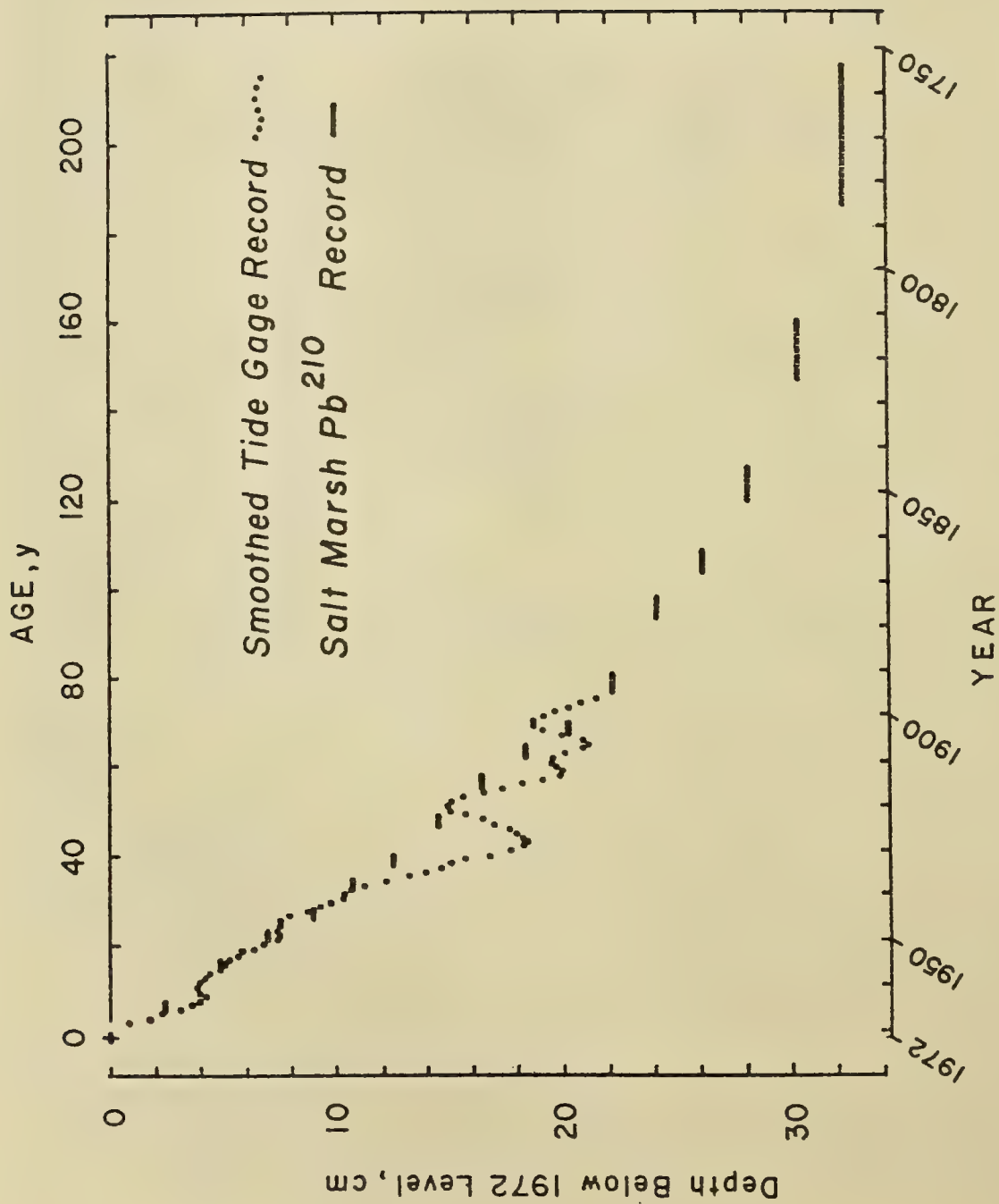


Figure 10-10. Correspondence of age of layers in the Farm River (Branford) salt marsh, determined by Pb-210 and sea level rise curve from tide gauge data (after McCaffrey, 1977, and McCaffrey and Thomson 1979). New Haven Harbor Ecological Studies Summary Report, 1979.

especially as the rate has not been constant over the past 100 years (Figure 10-10). In addition, these researchers showed that the calculated ^{210}Pb flux, as determined by the standing crop of unsupported ^{210}Pb in the salt marsh, equaled the atmospheric flux as determined for New Haven by Benninger (1978). This implies that: (1) the trace metal distribution vertically in the salt marsh reflects the changing flux over time and that no vertical migration of the trace metals is expected by diffusion or biological activity; and (2) that there should be an atmospheric flux of trace metals recorded in the growing salt marsh. Indeed the calculated flux of Cu, Pb and Zn (Figure 10-11) appears to be almost solely atmospheric as the predicted flux of these metals is in agreement with the estimated atmospheric flux (Table 10-1). That both the ^{210}Pb and trace-metal fluxes to the salt marsh can be ascribed almost completely to an atmospheric source is not surprising since the surface of a salt marsh, on which *Spartina alterniflora* grows, is inundated by sea water only about 5% of the time. The remainder of the time it behaves like an atmospheric collector.

The Interpretation of the Trace Metal Record in Long Island Sound Cores

We can now test the following question: how much of the trace metal content of Long Island Sound sediments may be explained by an atmospheric source? To answer the question, we integrate the total excess ^{210}Pb in a core with the integrated excess metal content. Benninger (1978) has shown that the ^{210}Pb content in Long Island Sound sediment is due predominantly to atmospheric supply and that there is no loss from the Sound. We then compare the ratio of integrated trace-metal content to integrated ^{210}Pb content found in a sediment core from the area under consideration to the ratio found by McCaffrey (1977) and McCaffrey and Thomson (1979) in the salt marsh. This normalization overcomes the problem of both horizontal and vertical mobility in the sediment. When such a calculation is made for the Long Island Sound long core (core 1148, Fig. 10-9) analyzed by Thomson, Turekian and McCaffrey (1975) it shows that all the Pb could be explained as of atmospheric origin, probably also most of the Zn and a smaller fraction of the

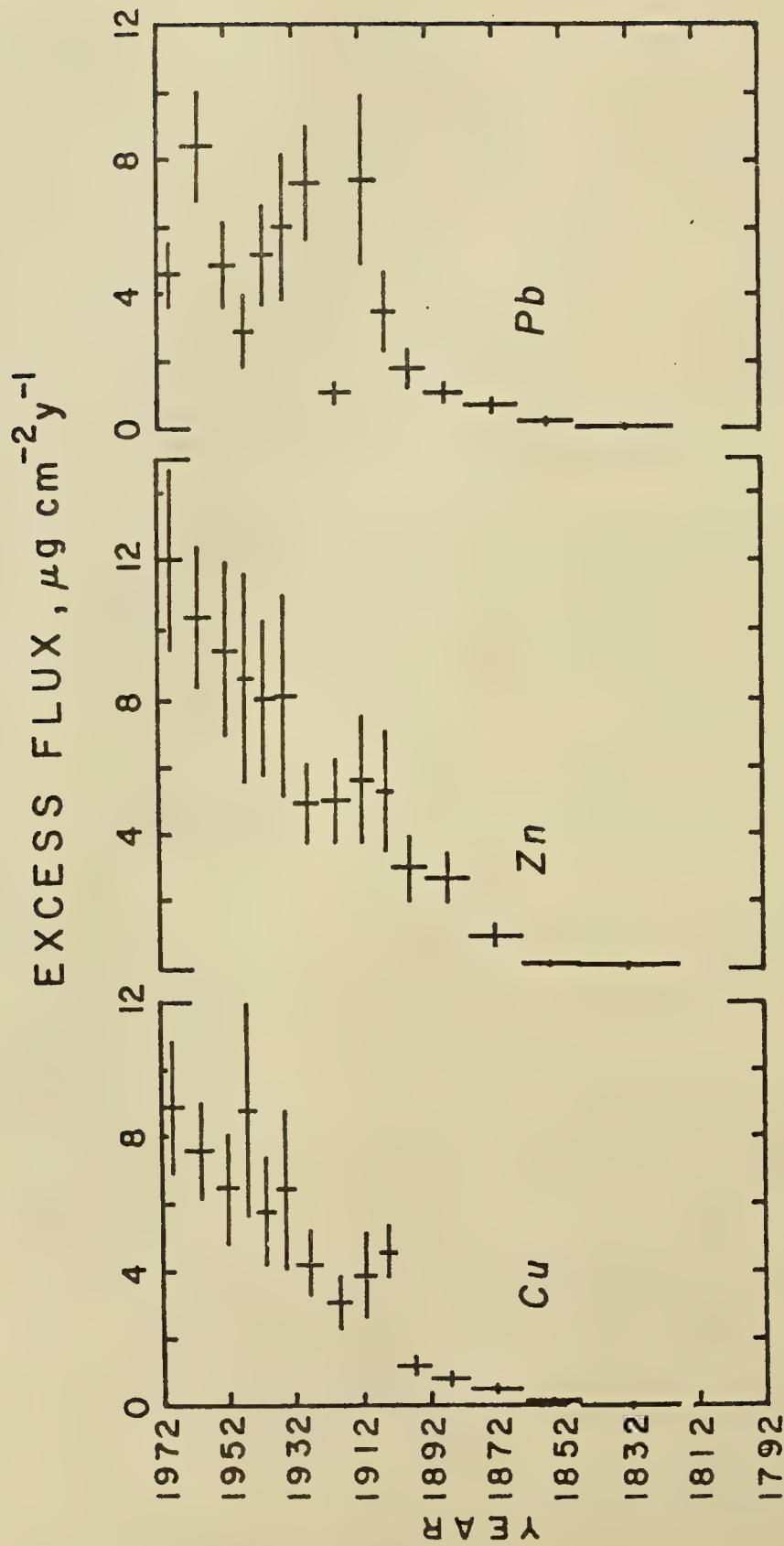


Figure 10-11. Flux of metals as of function of time in the Farm River salt marsh. (After McCaffrey, 1977 and McCaffrey and Thomson, 1979). New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 10-1. CALCULATED EXCESS METAL FLUX ($\mu\text{g}/\text{cm}^2/\text{yr}$) TO THE SURFACE OF THE FARM RIVER SALT MARSH COMPARED TO MEASURED ATMOSPHERIC DEPOSITION RATES AT SELECTED SITES. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

SITE AND COLLECTION DATA	Cu	Zn	Pb	REFERENCE
Branford, Ct. salt marsh (1977)	8 $\pm$ 2	12 $\pm$ 3	7 $\pm$ 4	McCaffrey (1977) and McCaffrey and Thomson (1979)
New York City (1969-1970)	9.8	32	35	Volchok and Bogen (1971)
Nantucket, Ma. (1966-1967)	5.6	7.6	8.5	Lazrus, Lorange and Lodge (1970)

copper. Thus, we conclude that the atmospheric burden of trace metals to the sediments of Long Island Sound is not trivial and indeed may be dominant for at least some elements.

The Kinetics of Trace-Metal Scavenging from the Water Column

The above discussion tacitly assumed that ^{210}Pb and the trace metals have a very short transit time as dissolved species in the water column. This implies efficient scavenging and removal of these nuclides from Long Island Sound. This hypothesis is supported by the results of Benninger (1978) on ^{210}Pb distribution in Long Island Sound waters. Figure 10-12 shows that virtually all of the ^{210}Pb in Long Island Sound waters is associated with particles. The dissolved ^{210}Pb concentration is nil. When this is compared to the much higher open-ocean surface-water concentrations (Nozaki, Thomson and Turekian, 1976), it is clear that nearshore processes quickly and effectively remove reactive chemical species from the water column. Aller and Cochran (1976) came to the same conclusion regarding ^{234}Th in Long Island Sound. Together these results imply that the mean residence time of reactive metals in the water of Long Island Sound with respect to removal into the sediments is of the order of days.

The agent of scavenging of the trace metals is almost certainly adsorption on particles rather than association with plankton. Table 10-2 shows how the flux of ^{210}Pb out of the ocean surface is ascribable almost totally to the effect of particle scavenging. Most other reactive elements probably behave in a similar fashion. Most of the particles in Long Island Sound are resuspended bottom sediments and probably include manganese and iron oxide coatings that are effective adsorbers of many trace metals.

Any geographic redistribution of elements in Long Island Sound is thus affected by the transport of particles from the moment of scavenging to final burial in the sediments (see Turekian, 1977 for a more detailed discussion). This generalization does not hold for manganese or iron completely as these elements (and others affected by coprecipita-

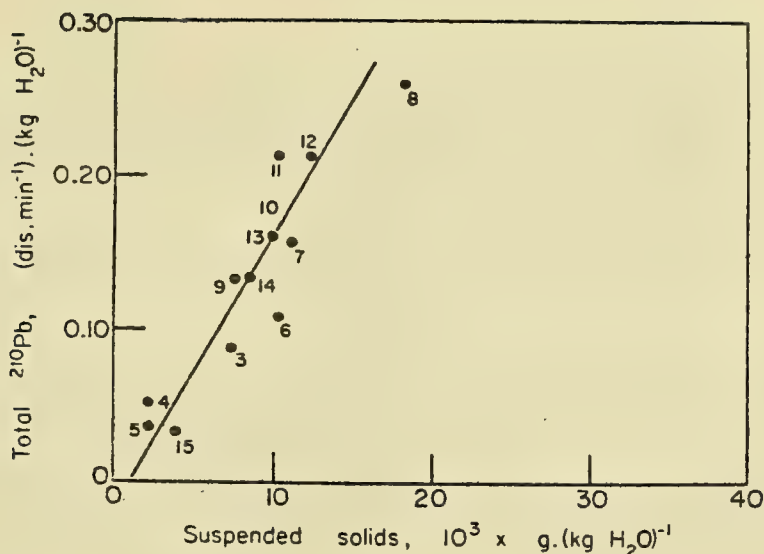


Figure 10-12. Total ^{210}Pb in surface water versus concentration of suspended solids taken over time at a station in central Long Island Sound. The plot shows that there is virtually no ^{210}Pb dissolved in Long Island Sound, having been effectively scavenged to the sediments on a very rapid time scale (After Benninger, 1978). New Haven Harbor Ecological Studies Summary Report, 1979.

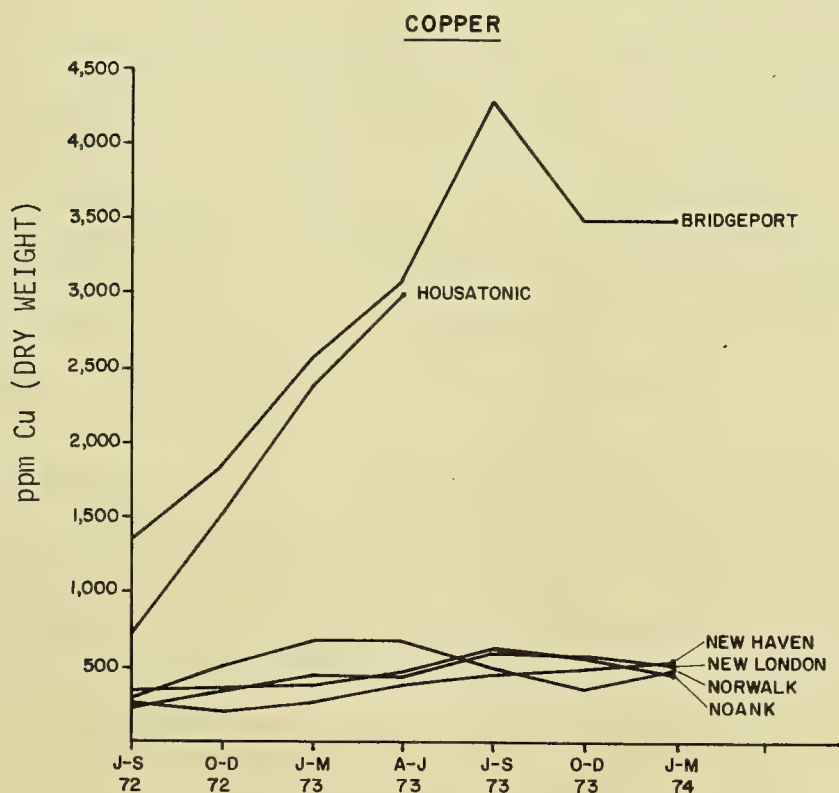


Figure 10-13. Copper concentration in oysters as a function of time at six locations along the Connecticut coast. (Plotted from the data of Feng and Ruddy, 1974). New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 10-2. ROLE OF PLANKTON IN ^{210}Pb TRANSPORT OUT OF THE OCEAN SURFACE LAYER. NEW HAVEN HARBOR ECOLOGICAL STUDIES, SUMMARY REPORT, 1979.

Type of Environment	Coastal: Long Island Sound (Benninger, 1976)	Open Ocean: North Pacific (Nozaki & Tsunogai, 1976)
Productivity g(dry wt) $\text{m}^{-2} \text{y}^{-1}$	1000	200
^{210}Pb in plankton dpm g^{-1} (dry wt)	<2	<5
^{210}Pb flux out of mixed layer dpm $\text{cm}^{-2} \text{y}^{-1}$	<0.2	0.1
^{210}Pb atmospheric flux dpm $\text{cm}^{-2} \text{y}^{-1}$	1.0	2.0
Percent transported by plankton settling*	<20%	<5%

* With residence times of a year or less the remaining ^{210}Pb must be transported by particles.

tion) are easily mobilized in solution under reducing conditions but their ultimate fate is burial in the sediment.

Summary of Controls on Trace Metal Distribution in Long Island Sound Sediments

There are three main sources of trace-metal supply to the sediments of Long Island Sound as stated above: (1) industrially derived metal-rich particles from streams draining into harbors and directly into the Sound; (2) sewer outfalls in coastal areas; and (3) atmospherically transported materials. In addition, it is possible to include trace-metal-rich dredge spoils from contaminated harbors and channels as a source analogous to the situation observed in the New York Bight.

The pattern of trace-metal distribution in the sediments of Long Island Sound follows, to a first approximation, the pattern of grain-size distribution - the trace-metal concentrations are highest, on the average, in the finest grained sediments. But the second order effect related to localized trace-metal inputs from contaminated rivers or from sewer outfalls can also be seen - in particular, the sediments of the western part of the Sound nearest to the highly impacted New York City area around Throgs Neck. Those in the area west of the Housatonic River estuary and those in New Haven Harbor are conspicuously higher in trace metals than surrounding sediments independent of grain size.

There is evidence from the distribution of energy at the bottom of the Sound (Bokuniewicz, Gebert and Gordon, 1976) that the top few millimeters of the fine-grained, metal-rich sediments, are resuspended and moved around the bottom of the Sound's central basin. This process would tend to homogenize the trace-metal concentrations at the sediment-water interface. When considering the ^{234}Th (24 day half life) standing crop distribution in the uppermost part of the sediment column in cores collected from different water depths (Aller, Benninger and Cochran, 1979), the time scale of this homogenization process is on the order of months.

The time frame for trace metals reaching their ultimate repositories in Long Island Sound then will be determined by the efficiency of burial of the trace metal-rich components deep in the sediment column out of the domain of surficial resuspension and redistribution. This burial is principally affected by deep burrowing organisms such as the Crustacea. Documentation comes from Benninger and Aller (1979) using plutonium as the man-made tracer (injected into the environment primarily in 1962 with secondary injections of smaller magnitude since then) and ^{210}Pb as the steady-state tracer. Table 10-3 is taken from their work and shows that sediments in the deeper parts of Long Island Sound have a larger standing crop of both of the nuclides than the sediments in the shallow area, principally due to transfer to greater depths in the sediment column. This implies that the deeper part of the basin is the dominant repository for trace metals introduced into the Sound because of deeper biological reworking.

TRACE METALS IN ORGANISMS

Observed Trace Metal Distributions in Mussels and Oysters from Long Island Sound

Mussels and oysters (epifauna) are filter feeders which attach to hard surfaces. Their isolation from the sediment means that their trace-metal compositions are likely to be reflective, primarily, of the suspended material in the water. The extent to which organisms more intimately associated with the sediment (infauna) also reflect the suspendable material can only be established by a comparison between these infaunal organisms and the hard substrate species like the oysters and the mussels. In this section, therefore, the data available on trace-metal concentrations in mussels and oysters from the Connecticut shore are reviewed.

TABLE 10-3. ^{210}Pb AND PLUTONIUM INVENTORIES IN LONG ISLAND SOUND
SEDIMENTS (BENNINGER AND ALLER, 1979). NEW HAVEN HARBOR
ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	NWC (14 m)	DEEP (34 m)
Long-term sediment accumulation rate*, cm y^{-1}	0.06	0.1
Pb-210 "sediment accumulation rate", cm y^{-1}	0.11	0.57
Dominant organisms	shallow-burrowing mobile deep-feeding deposit feeders	deep-burrowing sedentary shallow-deposit or suspension feeders
Excess ^{210}Pb inventory, dpm cm^{-2}	11.1	78.2
Plutonium inventory (1975), dpm cm^{-2}	0.22	0.86

* Based on the total thickness accumulated during the past 8000 years.

Feng and Ruddy (1974) made a detailed study of the composition of the soft tissue of oysters (*Crassostrea virginica*) harvested along the Connecticut coast. A single stock of oysters obtained as yearlings were transferred to six stations on the Connecticut coast: (1) Norwalk Harbor at the Northeast Utilities Company pier, (2) Bridgeport at the Pleasure Beach Bridge, (3) the Housatonic River below Devon, (4) New Haven Harbor at the Coast Guard Station finger pier, (5) New London Harbor at the U.S. Navy Underwater Systems Center pier and (6) Noank at the University of Connecticut Marine Sciences Institute pier. The stock was then sampled periodically between June 1972 and April 1974 and tissue analyzed for Cd, Cu, Hg, Mn and Zn. The oyster tissue did not vary significantly in the concentration of these elements from the native oysters also analyzed. The highest values for all of the trace elements except mercury are found at the Bridgeport and Housatonic sites.

Figures 10-13 - 10-15 show the changes in composition with time, at each of the six locations, for Zn, Cd and Cu, respectively. There is clearly a marked increase from the summer of June 1972 to the winter of 1974 for the Housatonic-Bridgeport region for all metals and a marked increase for zinc for all other locations except Norwalk which seems to have gone through a maximum in the winter or spring of 1973.

Mussels

Trace metals in Long Island Sound mussels were determined at Yale University (Curran, 1976 and additional data)*. A map of the sampling locations is shown in Figure 10-16. The geographic variations of trace metals in native mussels collected in 1975 show (Figures 10-17.- 10-21) the same patterns as the oysters although the concentrations are considerably lower in the mussels. The pattern holds for all the trace metals analyzed including Pb and Ni as well as Zn, Cd and Cu. The other region of high metal concentration in the mussels is the area around Throgs Neck.

* The analytical methods used at Yale have been reported in the 1975 Annual Report to the United Illuminating Company through Normandeau Associates, Inc.

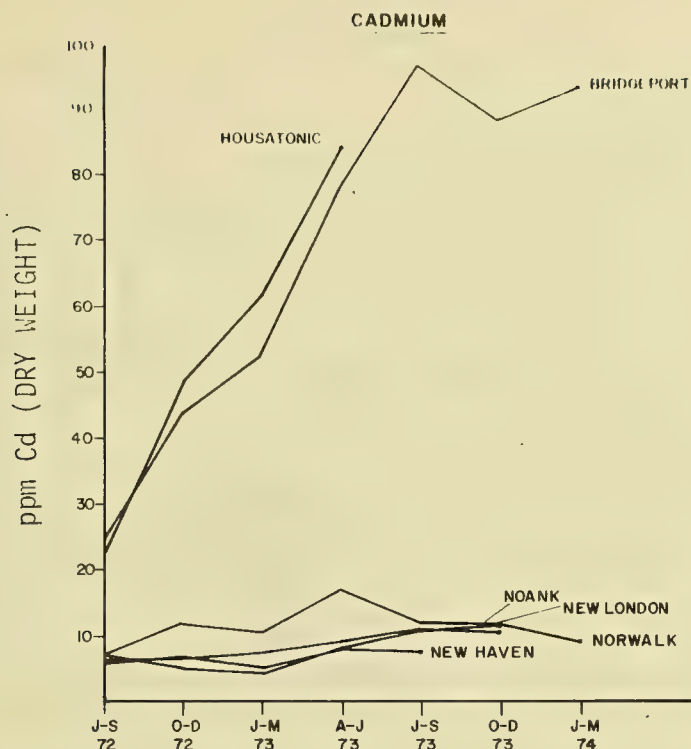


Figure 10-14. Cadmium concentration in oysters as a function of time at six locations along the Connecticut coast. (Plotted from the data of Feng and Ruddy, 1974). New Haven Harbor Ecological Studies Summary Report, 1979.

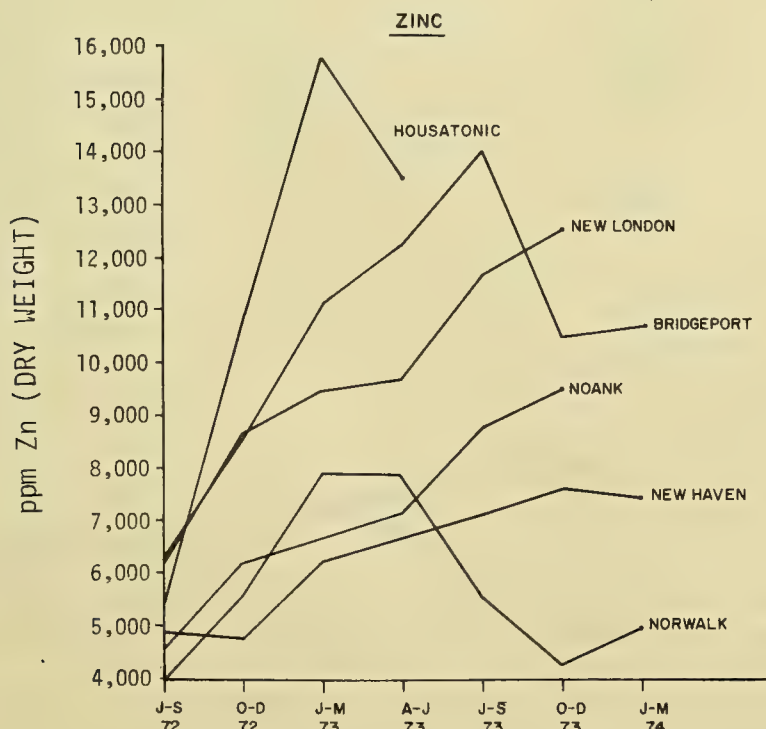


Figure 10-15. Zinc concentration in oysters as a function of time at six locations along the Connecticut coast. (Plotted from the data of Feng and Ruddy, 1974). New Haven Harbor Ecological Studies Summary Report, 1979.



Figure 10-16. Sampling locations for mussels studied for trace metals (Collected by D. Curran of Yale). New Haven Harbor Ecological Studies Summary Report, 1979.

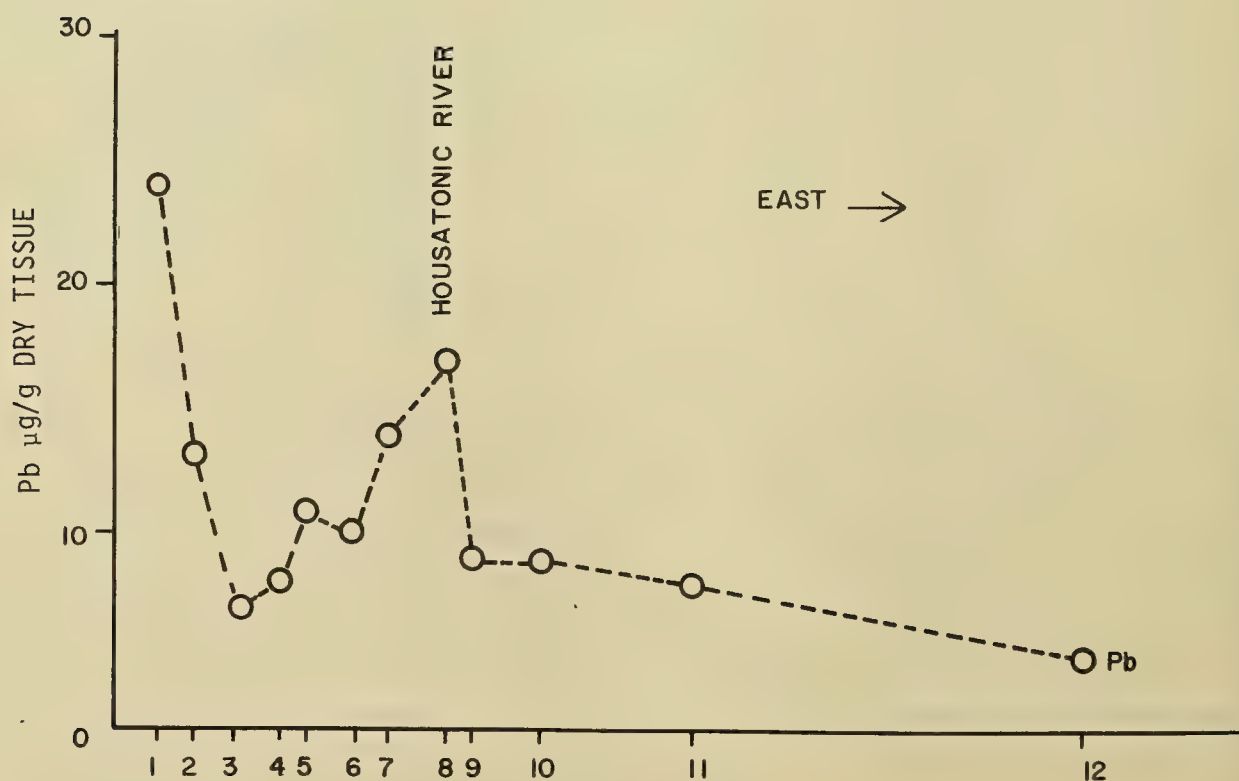


Figure 10-17. Lead concentration of dry soft tissues of mussels as a function of location along the Connecticut coast. (See Figure 16 for locations, after Curran, 1976). New Haven Harbor Ecological Studies Summary Report, 1979.

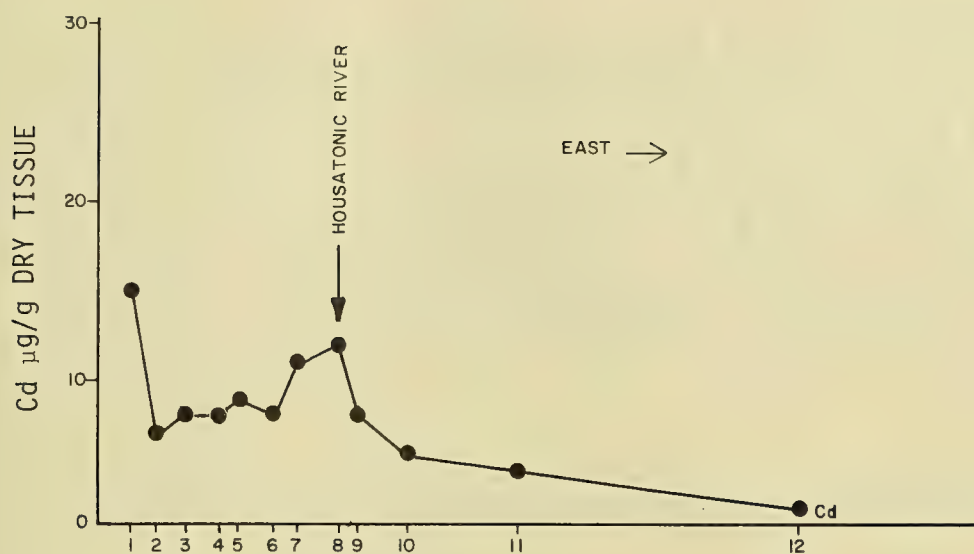


Figure 10-18. Cadmium concentration of dry soft tissues of mussels as a function of location along the Connecticut coast. (See Figure 16 for locations, after Curran, 1976). New Haven Harbor Ecological Studies Summary Report, 1979.

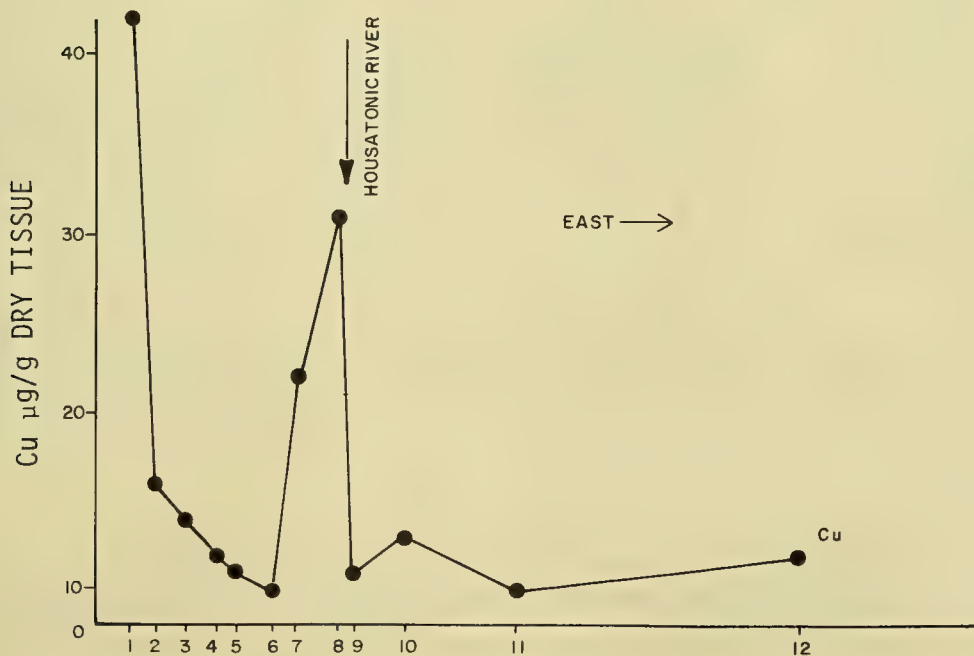


Figure 10-19. Copper concentration of dry soft tissues of mussels as a function of location along the Connecticut coast. (See Figure 16 for locations, after Curran, 1976). New Haven Harbor Ecological Studies Summary Report, 1979.

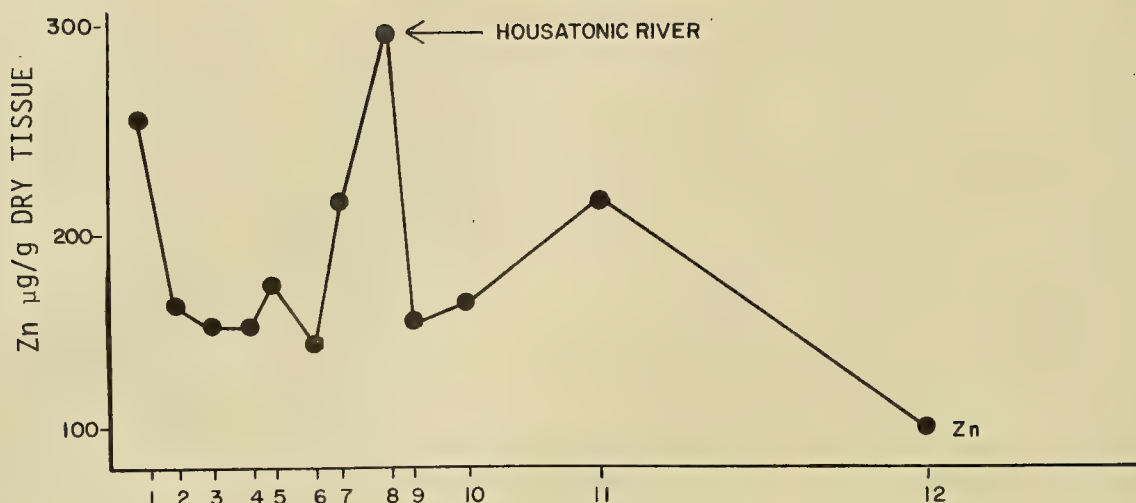


Figure 10-20. Zinc concentration of dry soft tissues of mussels as a function of location along the Connecticut coast. (See Figure 16 for locations, after Curran, 1976). New Haven Harbor Ecological Studies Summary Report, 1979.

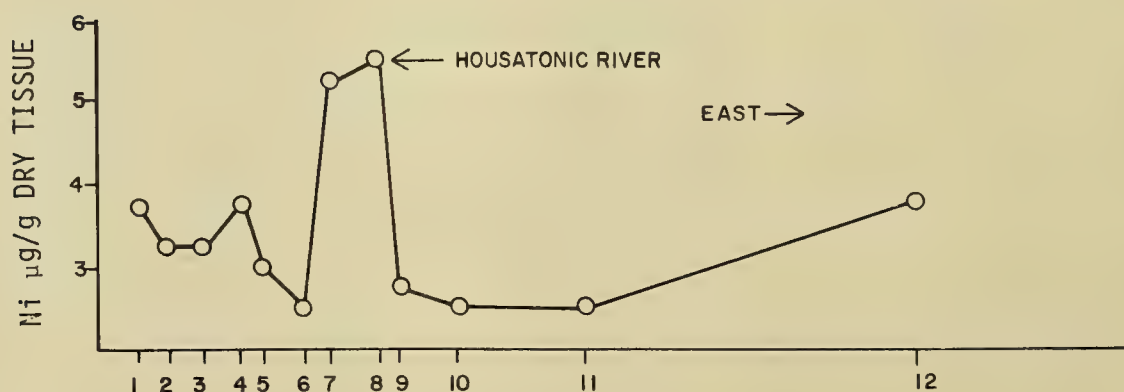


Figure 10-21. Nickel concentration of dry soft tissues of mussels as a function of location along the Connecticut coast. (See Figure 16 for locations, after Curran, 1976). New Haven Harbor Ecological Studies Summary Report, 1979.

The Cause of the Observed Trace-Metal Distributions

Obviously both oyster and mussel tissue composition are influenced by the trace-metal content of the particles they ingest. There should then be a relationship between the chemical properties of the particles of the surrounding water and the sediments and the compositions of the tissues. Consequently, the chemical composition of the ingestible particles could be inferred from two environmental indicators: the composition of the sediments at the sediment-water interface, and the composition of the bulk water (including the fine-grained particles) associated with the organisms.

Considering the trace-metal maps for the top five cm of Long Island Sound sediment cores (Figures 10-5-7), there is a marked similarity between the areas of high metal concentrations in the sediments and high concentrations in the mussels and oysters. Similarly, a comparison of the Ni concentrations in mussels (Figure 10-21) with the coastal distribution of Ni in unfiltered Long Island Sound water (Figure 10-22) also shows a marked correlation. [Nickel is the only element analyzed in the mussel study which has also been extensively analyzed in water samples from along the Connecticut coast (Turekian, 1971)]. I conclude that the primary source of the metals found in elevated levels in the soft tissues of mussels and oysters is the suspended organic-rich debris in the Sound. This is accentuated where a significant source of metal-bearing organic-rich particles from human activities is introduced by direct supply or secondary resuspension. Therefore, a strong correlation exists between high metal concentrations in all components of the coastal system -- water, sediment and organisms and the proximity of freshwater stream and sewer discharges.

Redistribution of particulate material from point and in part non-point (i.e., atmospheric) injections occurs in the sediments of the Sound. Subsequent dilution of this high-metal-content particulate matter with indigenously produced, low-metal-content planktonic debris plus material from "cleaner" sediments in the Sound acts to obscure point sources. This occurs within a relatively short distance (one - two miles) from the point of injection.

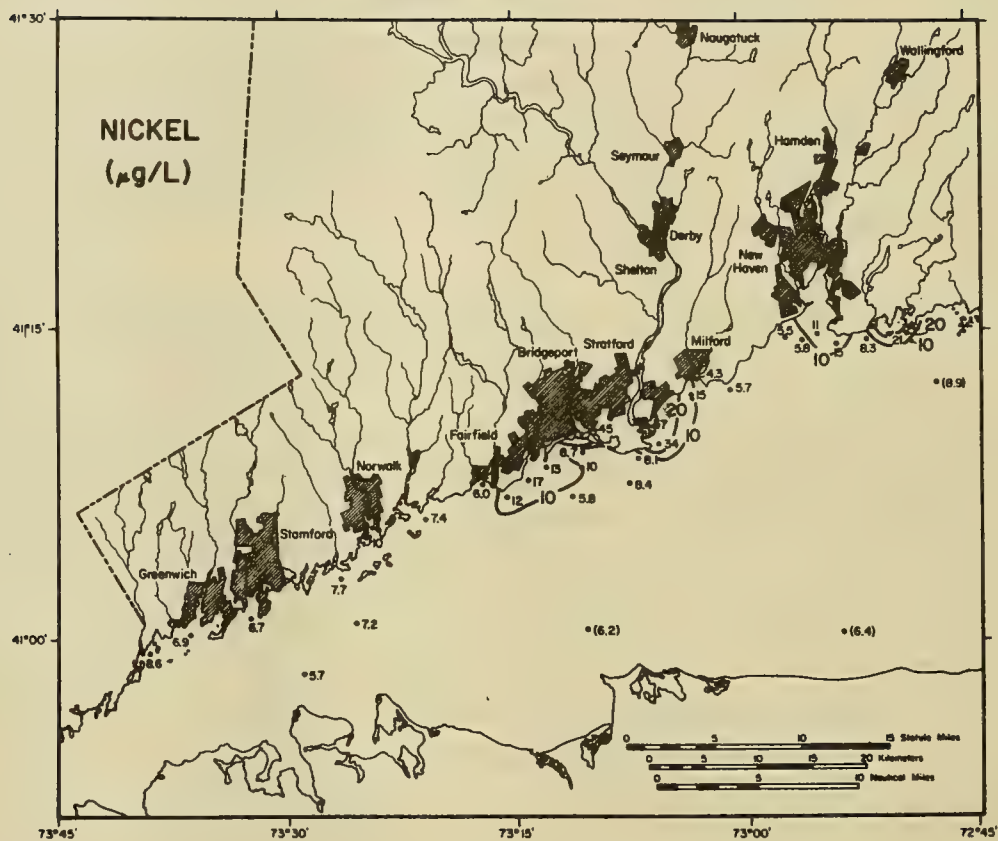


Figure 10-22. Distribution of Nickel in unfiltered surface waters of Long Island Sound (after Turekian, 1971). New Haven Harbor Ecological Studies Summary Report, 1979.

Time Variations in Mercenaria and Crassostrea from New Haven Harbor

Metals analysis of soft tissue from *Mercenaria mercenaria* (the hard-shell clam) have been conducted periodically using specimens from the New Haven Harbor site and Morris Cove, New Haven Harbor, since the summer of 1974. Sampling was performed concurrently with the Rhoads and Michael investigations (see Section 6.0 Benthos) as part of the study to meet the requirements of Section 4(A)(2) of the NPDES discharge permit. The two sample locations are on either side of the Coast Guard Station location that was utilized in the oyster study conducted by Feng and Ruddy (1974) discussed above. Statistical analysis of the data presented in Table 4 shows no significant difference ($p < 0.05$) in concentrations between the two sites and over time except in the case of lead. The higher values for lead at the Harbor Station site are possibly related to the site's proximity to the East Shore Sewage Treatment Plant Outfall. This is based on data presented earlier showing higher rates of metals accumulation in organisms near point sources. The *Mercenaria* are primarily affected by the ingestion of suspended organic matter, high in metals, from sewer outfalls, rather than by the surrounding sediments.

Levels of copper, cadmium and zinc in oysters maintained in New Haven Harbor (Figures 10-13 - 10-15) follow trends observed in other harbors along the Connecticut shore. With the exception of zinc, concentrations remained relatively constant over the two-year period studied.

Trace-Metals Composition Comparisons Among Organisms from New Haven Harbor

It has been already noted that oysters and mussels concentrate trace elements to different extents by ingesting edible particles; oysters generally possess higher metal content than mussels. Comparisons have also been made between several other species.

Table 10-5 shows a comparison of metal concentrations in five species of bivalves collected in New Haven Harbor. Of the five bivalves, two (*Crassostrea* and *Mytilus*) are considered as epifauna and the remaining three (*Mercenaria*, *Mulinia* and *Yoldia*) are considered as infaunal species.

TABLE 10-4. TIME VARIATION IN CONCENTRATIONS OF Cu, Pb, Zn, Cd AND Hg IN SOFT TISSUE OF *MERCENARIA MERCENARIA* AT TWO SITES IN NEW HAVEN HARBOR. (ALL CONCENTRATIONS IN $\mu\text{g/g}$ OF DRY SAMPLE). NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

SITE	SEDIMENT $\mu\text{g/g}$	SAMPLING TIME				
		SUMMER 1974	WINTER 1974-75	SUMMER 1975	SUMMER 1976	WINTER 1976-77
Morris Cove (control site)	(summer 1974)					
Number analyzed	3	3	6	3	5	5
LOI* (%)	5.7					
Cu	39	21	22	18	26	21
Pb	26	4.3	6.9	3.7	2.5	2.8
Zn	113	157	198	271	116	137
Cd		1.3	2.5	1.6	0.84	1.0
Hg	0.12	0.33	0.2			
UI (Coke Works Site)						
Number analyzed	2	3	6	7	5	5
LOI*	5.6					
Cu	16	24	35	16	31	24
Pb	16	6.0	12.8	5.6	4.5	3.2
Zn	100	184	379	265	145	165
Cd		1.3	2.4	1.5	1.6	1.4
Hg	0.10	0.76	1.6			

* LOI = Loss on ignition $\approx$ organic matter

TABLE 10-5. COPPER AND ZINC CONCENTRATIONS ($\mu\text{g/g}$ OF DRY SOFT TISSUE) OF DIFFERENT BIVALVE SPECIES AT VARIOUS LOCATIONS IN NEW HAVEN HARBOR. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

LOCATION IN NEW HAVEN HARBOR:	MORRIS COVE	UI COKE WORKS	COAST GUARD STATION	CHANNEL
YEAR OF COLLECTION:	SUMMER 1975 (1)	SUMMER 1975 (1)	1972-1974 (2)	1973 (3)
<u>COPPER</u>				
<i>Mercenaria</i>	18	16		
<i>Mytilus</i>	12	23		
<i>Crassostrea</i>			460	
<i>Mulinia</i>				19
<i>Yoldia</i>				14
<u>ZINC</u>				
<i>Mercenaria</i>	271	265		
<i>Mytilus</i>	268	270		
<i>Crassostrea</i>			5800	
<i>Mulinia</i>				31
<i>Yoldia</i>				43

(1) From Table 4

(2) From Feng and Ruddy (1974)

(3) Samples collected and analyzed at Yale University in conjunction with an environmental study for dredging in connection with the construction of the United Illuminating Harbor Station site.

Yoldia is a deposit feeder and *Mulinia* a suspension feeder. Both species are primarily influenced by the material at the sediment water interface. In contrast, *Crassostrea*, *Mytilus* and *Mercenaria* are most sensitive to the metal-rich organic matter making up the primary particle flux.

Data collected from the Harbor show *Crassostrea* accumulating the greatest levels of the trace metals measured. In general, zinc was accumulated to a much greater degree than copper.

Of interest is the possible correlation between diet and metal concentrations in the bivalves studied assuming no specific biologically-mediated internal fractionation of metals in these organisms. Oysters apparently readily assimilate the primary metal-rich organic debris derived from fresh water sources; mussels and *Mercenaria*, with a lower concentration of heavy metals, ingest a mixture of high concentrations of this primary material and lower concentrations of secondary planktonic debris and resuspended sediments, whereas the two small clams with low metal concentrations derive their nourishment principally from resuspended sediment with its characteristically lower metal concentrations.

Trace-Metals Composition of Organisms in the Central Basin of Long Island Sound

Infauanal Bivalves

A rich infauna is associated with the sediment of the deeper waters of Long Island Sound. These species are not normally regarded as a human food resource but some fish and lobsters depend in part on these organisms as a food source. We focus attention on two deposit feeding bivalves, *Yoldia* and *Nucula*, and two suspension feeders, *Mulinia* and *Pitar*. Table 10-6 shows a comparison among these species from samplings in the central Long Island Sound basin and New Haven Harbor, and reveals relatively little difference in bivalve-tissue metals composition between the two areas.

TABLE 10-6. TRACE ELEMENTS IN SMALL SEDIMENT-DWELLING CLAMS FROM NEW HAVEN HARBOR AND CENTRAL LONG ISLAND SOUND. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	$\mu\text{g/g}$ DRY SOFT TISSUE	
	Zn	Cu
<u>Deposit feeders</u>		
<i>Yoldia</i> New Haven Harbor (2)	43	14
Long Island Sound (7)	36	18
<i>Nucula</i> Long Island Sound (1)	28	49
<u>Suspension feeders</u>		
<i>Mulinia</i> New Haven Harbor (5)	31	19
Long Island Sound (12)	26	23
<i>Pitar</i> Long Island Sound (6)	25	12

() indicates number of individuals analyzed

Anemones

This group of organisms is unique in that its members expose a large amount of mucus-like tissue to seawater at the sediment-water interface. Not only is it able to sequester particles rich in elements but the mucopolysaccharide composition of this material acts as a scavenger for trace elements from seawater as well. This may explain the very high concentration of trace metals in these organisms. A comparison of the trace-element composition of an anemone (species unknown) from 2500 meters depth in the Mid-Atlantic Ridge with that of *Cerianthus americanus*, (common in Long Island Sound) shows that they are within a factor of 3 to 9 of each other in concentration for the elements analyzed. This implies that trace metal sequestering is a property of this organism wherever it is found (Table 10-7) and not constrained by the peculiar chemistry of the substrate.

TABLE 10-7. COMPOSITION OF ANEMONES FROM LONG ISLAND SOUND (LIS) AND THE MID-ATLANTIC RIDGE (MAR). NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	$\mu\text{g/g}$ DRY SOFT TISSUE			
	Zn	Cu	Pb	Cd
LIS <i>Cerianthus</i> (7)	736	89	4.1	4.6
MAR <i>Anemone</i> (species unknown) (1) (2500 meters depth)	143	10	14	0.85

() indicates number of individuals analyzed

ANALYSIS OF IMPACTS

The supply of trace metals from domestic and industrial sewage is imprinted on the sediments adjacent to the source of impact as we have seen in the first section. The organisms feeding on suspended organic material respond in their trace-metal concentration to this input. New Haven Harbor is one such impacted area but does not influence the biota as strongly as the Housatonic River or Throgs Neck (East River) systems. Changes in trace-metal supply with time exist in some locations around the Sound, but they are not marked in New Haven Harbor as reflected in the long time-scale study of *Mercenaria mercenaria* at two sites in the harbor.

The role of New Haven Harbor Station as a potential source of trace-metal input in New Haven Harbor is limited. Surface runoff from the plant site and leachate from the percolation lagoon that receives treated plant wastes are the most probable sources. The addition of trace metals to the condenser cooling water during plant passage is effectively eliminated since the condenser tubes are titanium, a metal extremely resistant to corrosion and erosion and the tubesheets are aluminum with bronze epoxy-coating. Contributions from plant-site runoff, consisting primarily of dust particles and other material from atmospheric sources, is not expected to be different from other similar-sized land areas around the harbor. The percolation lagoon receives treated effluents from such in-plant sources as floor drains and demineralizer regeneration wastes. The leaching of trace metals from the percolation lagoon into the harbor is dependent upon the composition (permeability and sediment type) of soils underlying the lagoon. Any contribution from this source would enter the harbor via the groundwater, most probably in the vicinity of the plant waterfront and the drainage ditch located to the south of the plant property line. This contribution would be insignificant compared to metals entering the harbor from the adjacent sewer outfall.

As the long time-scale study (Table 10-4) covers several years which bracket the construction and operation of the New Haven Harbor United Illuminating power plant, it is evident that the impact of this plant on the biota of the region is not measurable so far as the trace metals are concerned.

SUMMARY AND CONCLUSIONS

Long Island Sound

Trace metals are supplied to Long Island Sound by three pathways: (1) atmosphere, (2) metal-rich particles from contaminated undammed streams directly leading into the Sound and (3) trace-metal-rich organic particles derived from sewer outfalls that debouch into harbors.

Mussels and oysters growing on hard substrates along the shores of Long Island Sound utilize and reflect the trace-metal-enriched particles associated with the second two sources.)

These trace-metal-rich sources also imprint themselves on the bottom sediments although the bottom circulation in the Sound tends to mobilize and homogenize the sediment at the sediment-water interface.

Over a long timeframe the sediments of the deeper parts of Long Island Sound serve as the principal repository for trace metals injected into the Sound due to the higher frequency of deep distribution by Crustacea in sediments found in deeper waters.

New Haven Harbor

Trace metals enter New Haven Harbor from the Quinnipiac River, major sewer outfalls located near Long Wharf and New Haven Harbor Station as well as from the atmosphere. The dominant source is the

sewer outfalls. New Haven Harbor sediments, therefore, contain high metal concentrations relative to greater Long Island Sound because of discharges from several sewage treatment plants. Any contribution from the New Haven Harbor is relatively small and obscured by contributions from the sewer outfalls.

Soft tissue of *Crassostrea virginica* showed lower levels of trace metals in New Haven Harbor oysters than in five other Long Island Harbors studied. Suspension and deposit feeding molluscs showed slightly higher zinc in New Haven Harbor, but lower copper relative to Long Island Sound. *C. virginica* showed higher concentrations of these metals than other bivalves analyzed including *Mercenaria mercenaria* and *Mytilus edulis*.

Trace-metal concentrations did not show a pronounced seasonal or spatial pattern in *Mercenaria mercenaria* soft tissue in New Haven Harbor.

Impact from New Haven Harbor Station on the trace-metal regime in New Haven Harbor, if present, is overwhelmed by the ambient long-term trace metal supply and removal patterns.

ACKNOWLEDGMENTS: This research was supported by the United Illuminating Company and the Department of Energy. Various students at Yale participated in the analytical program. They are R. J. McCaffrey, D. Curran, J. K. Cochran, D. M. DeMaster, L. K. Benninger and G. Papia.

REFERENCES CITED

- Aller, R.C. and J.K. Cochran. 1976. $^{234}\text{Th}/^{238}\text{U}$ disequilibrium in near-shore sediment: particle reworking and diagenetic time scales. *Earth Planet. Sci. Letters* 29:37-50.
- _____, L.K. Benninger and J.K. Cochran. 1979. Tracking particle associated processes in near-shore environments by use of $^{234}\text{Th}/^{238}\text{U}$ disequilibrium. In preparation.
- Applequist, M.D., A. Katz and K.K. Turekian. 1972. Distribution of mercury in the sediments of New Haven (CT) Harbor. *Environ. Sci. Tech.* 6:1123-1124.
- Benninger, L.K. 1976. The use of uranium-series radionuclides as tracers of geochemical processes in Long Island Sound. Ph.D. Thesis, Yale University.
- _____. 1978. ^{210}Pb balance in Long Island Sound. *Geochem. Cosmochim. Acta* 42:1165-1174.
- _____ and R.C. Aller. 1979. ^{234}Th , ^{210}Pb and plutonium inventories in sediments of Long Island Sound as a function of macrobenthic community. In preparation.
- _____, D.M. Lewis and K.K. Turekian. 1975. The use of natural Pb-210 as a heavy metal tracer in the river-estuarine system. p. 202-210 *IN: T.M. Church (ed.). Marine Chemistry in the Coastal Environment. American Chemical Society Symposium Series 18.*
- _____, A.C. Aller, J.K. Cochran and K.K. Turekian. 1979. Effects of biological sediment mixing on the ^{210}Pb chronology and trace metal distribution in a Long Island Sound sediment core. *Earth Planet. Sci. Letters*. In press
- Bokuniewicz, H.J., J. Gebert and R.B. Gordon. 1976. Sediment mass balance in a large estuary (Long Island Sound). *Estuar. Coast. Mar. Sci.* 4:523-536.
- Carmody, D.J., J.B. Pearce and W.E. Yasso. 1973. Trace metals in sediments of the New York Bight. *Mar. Pollut. Bull.* 4:132-135.
- Curran, D. 1976. Use of the blue mussel, *Mytilus edulis*, as an indicator for heavy metal pollutants in Long Island Sound. Unpublished Senior Thesis, Yale University.
- Feng, S.Y. and G.M. Ruddy. 1974. Zn, Cu, Cd, Mn, and Hg in oysters along the Connecticut coast. p. 132-161. *IN: Final Report to Office of Sea Grant Programs by the University of Connecticut Marine Sciences Institute.*

- Grieg, R.A., R.N. Reid and D.R. Wenzloff. 1977. Trace metal concentrations in sediments from Long Island Sound. *Mar. Pollut. Bull.* 8:183-188.
- Gross, M.G. 1976. Sources of urban waste. p. 150-161. IN: M.G. Gross (ed). *Middle Atlantic Continental Shelf and the New York Bight*. Am. Soc. Limn. Oceanog. Spec. Symp. 2.
- Lazrus, A.L., E. Lorange, and J.P. Lodge, Jr. 1970. Lead and other metal ions in precipitation. *Environ. Sci. Tech.* 4:55-58.
- Lewis, D.M. 1977. The use of ^{210}Pb as a heavy metal tracer in the Susquehanna River system. *Geochem. Cosmochim. Acta.* 41:1557-1564.
- McCaffrey, R.J. 1977. A record of the accumulation of sediment and trace metals in a Connecticut, U.S.A., salt marsh. Ph.D. Thesis, Yale Univ.
- _____ and J. Thomson. 1979. The use of ^{210}Pb in determining fluxes to a Connecticut salt marsh. In preparation.
- Nozaki, Y. and S. Tsunogai. 1976. ^{226}Ra , ^{210}Pb and ^{210}Po disequilibrium in the western North Pacific. *Earth Planet. Sci. Letters.* 32:313-321.
- _____, J. Thomson and K.K. Turekian. 1976. The distribution of ^{210}Pb and ^{210}Po in the surface waters of the Pacific Ocean. *Earth Planet. Sci. Letters.* 32:304-312.
- Sholkovitz, E.R. 1976. Flocculation of dissolved organic and inorganic matter during the mixing of river water and seawater. *Geochim. Cosmochim. Acta.* 40:831-845.
- Thomson, J., K.K. Turekian and R.J. McCaffrey. 1975. The accumulation of metals in and release from sediments of Long Island Sound. p. 28-44 IN: L.E. Cronin (ed). *Estuarine Research Volume 1*. Academic Press.
- Turekian, K.K. 1971. Rivers, tributaries and estuaries. p. 9-73. IN: D.W. Hood (ed) *Impingement of Man on the Ocean*. Wiley.
- _____. 1977. The fate of metals in the oceans. *Geochim. Cosmochim. Acta.* 41:1139-1144.
- Volchok, H.L. and D. Bogen. 1971. Trace metals - fallout in New York City. p. I-91 to I-107. IN: Health and Safety Laboratory Fallout Program Quarterly Summary Report, U.S.A.C.E., April 1, 1971, New York, N.Y.

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

11.0 FINFISH OF NEW HAVEN HARBOR

By David N. Pease,
Neil B. Savage and Christopher J. Schmitt
Normandeau Associates, Inc.
Bedford, N. H.

TABLE OF CONTENTS

	PAGE
<i>INTRODUCTION.</i>	11-1
<i>Review of Comparable Studies.</i>	11-1
<i>METHODS</i>	11-5
<i>Otter Trawl Sampling.</i>	11-7
<i>Gill Net Sampling</i>	11-7
<i>Shore-Zone Seining.</i>	11-8
<i>Monitoring of Impingement</i>	11-8
<i>Ichthyoplankton</i>	11-8
<i>Processing of Specimens</i>	11-8
<i>CHARACTERIZATION OF NEW HAVEN HARBOR ICHTHYOFAUNA</i>	11-9
<i>Distribution of New Haven Harbor Ichthyofauna</i>	11-9
<i>Summary of Representative Species</i>	11-93
<i>ANALYSIS OF IMPACTS</i>	11-99
<i>Passage Through the Cooling Water System: Pumped Entrainment</i> .	11-102
<i>Impingement</i>	11-106
<i>Thermal Addition.</i>	11-109
<i>Impact.</i>	11-111
<i>LITERATURE CITED.</i>	11-115

LIST OF FIGURES

	PAGE
11-1. Finfish samples taken through October 1977 using gill nets, seine nets, and otter trawls (stations as indicated).	11-6
11-2. Relative abundance of dominant shore-zone fishes, April 1971 through October 1977	11-16
11-3. Monthly mean abundance of <i>Pseudopleuronectes americanus</i> collected by otter trawl from May 1971 through October 1977.	11-22
11-4. Total length (mean, range and std. dev.) of <i>Pseudopleuronectes americanus</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977	11-23
11-5. Mean daily impingement of winter flounder (<i>Pseudopleuronectes americanus</i>) by month at the New Haven Harbor Station, August 1975 through October 1977. . . .	11-25
11-6. Total length (mean, range and std. dev.) of <i>Scophthalmus aquosus</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-28
11-7. Monthly mean abundance of <i>Scophthalmus aquosus</i> collected by otter trawl from May 1971 through October 1977.	11-30
11-8. Total length (mean, range and std. dev.) of <i>Tautoglabrus adspersus</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977	11-33
11-9. Monthly mean abundances of <i>Tautoglabrus adspersus</i> collected by trawl from May 1971 through October 1977.	11-35
11-10. Monthly mean abundance of <i>Stenotomus chrysops</i> collected by trawl from May 1971 through October 1977.	11-37

11-11.	Total length (mean, range and std. dev.) of <i>Stenotomus chrysops</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-38
11-12.	Monthly mean abundance of <i>Paralichthys dentatus</i> collected by seine, gill net and otter trawl from May 1971 through October 1977	11-41
11-13.	Total length (mean, range and std. dev.) of <i>Paralichthys dentatus</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977	11-43
11-14.	Monthly mean abundance of <i>Clupea harengus</i> collected by gill net and otter trawl from May 1971 through October 1977.	11-46
11-15.	Total length (mean, range and std. dev.) of <i>Clupea harengus</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-47
11-16.	Monthly mean abundance of <i>Brevoortia tyrannus</i> collected by seine and gill net from May 1971 through October 1977.	11-50
11-17.	Total length (mean, range and std. dev.) of <i>Brevoortia tyrannus</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977	11-51
11-18.	Mean daily impingement of menhaden (<i>Brevoortia tyrannus</i>) by month at the New Haven Harbor Station; August 1975 through October 1977.	11-54
11-19.	Total length (mean, range and std. dev.) of <i>Alosa pseudoharengus</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-56
11-20.	Monthly mean abundance of <i>Alosa pseudoharengus</i> collected by gill nets and otter trawls from 1971 through 1977.	11-59
11-21.	Total length (mean, range and std. dev.) of <i>Alosa aestivalis</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-60

11-22.	Monthly mean abundance of <i>Alosa aestivalis</i> collected by gill nets and otter trawls from 1971 through 1977. .	11-62
11-23.	Total length (mean, range and std. dev.) of <i>Osmerus mordax</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-65
11-24.	Monthly mean abundance of <i>Osmerus mordax</i> collected by gill nets and otter trawls from 1971 through 1977. .	11-67
11-25.	Monthly mean abundance of <i>Alosa sapidissima</i> collected by gill nets and otter trawls from 1971 through 1977. .	11-68
11-26.	Total length (mean, range and std. dev.) of <i>Anchoa mitchilli</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-70
11-27.	Monthly mean abundance of <i>Anchoa mitchilli</i> collected by trawls from 1971 through 1977.	11-72
11-28.	Monthly mean abundance of <i>Scomber scombrus</i> collected by gill net and otter trawl from May 1971 through October 1977.	11-75
11-29.	Total length (mean, range and std. dev.) of <i>Scomber scombrus</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-76
11-30.	Total length (mean, range and std. dev.) of <i>Cynoscion regalis</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-80
11-31.	Monthly mean abundance of <i>Cynoscion regalis</i> collected by gill net and otter trawl from May 1971 through October 1977.	11-82
11-32.	Mean daily impingement of weakfish (<i>Cynoscion regalis</i>) by month at the New Haven Harbor Station; August 1975 through October 1977.	11-84
11-33.	Monthly mean abundance of <i>Pomatomus saltatrix</i> collected by seine and gill net from May 1971 through October 1977.	11-85

11-34.	Total length (mean, range and std. dev.) of <i>Pomatomus saltatrix</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-86
11-35.	Total length (mean, range and std. dev.) of <i>Morone saxatilis</i> captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977.	11-90
11-36.	Monthly mean abundance of <i>Morone saxatilis</i> collected by seine and gill net from May 1971 through October 1977.	11-92

LIST OF TABLES

		PAGE
11-1.	RATIONALE FOR SELECTION OF NEW HAVEN FINFISH SPECIES ADDRESSED INDIVIDUALLY.	11-10
11-2.	LIST OF FINFISH SPECIES COLLECTED IN NEW HAVEN HARBOR, APRIL 1970 THROUGH OCTOBER 1977	11-12
11-3.	IMPACT OF PASSAGE THROUGH THE COOLING WATER SYSTEM FOR FISH SPECIES FROM NEW HAVEN HARBOR, CONNECTICUT . .	11-104
11-4.	MEAN DAILY IMPINGEMENT OF FINFISH BY MONTH AT NEW HAVEN HARBOR STATION, AUGUST 1975 THROUGH OCTOBER 1977.	11-107
11-5.	IMPACT OF IMPINGEMENT ON REPRESENTATIVE IMPORTANT SPECIES	11-108
11-6.	SUBLETHAL EFFECTS OF DELIBERATE PROLONGED EXPOSURE TO THERMAL PLUME CONDITIONS. (FROM de SYLVA, 1969 AND KINNE, 1970).	11-112
11-7.	RELATIVE ABUNDANCE OF REPRESENTATIVE SPECIES COMPARED BY MONTH BETWEEN OPERATIONAL AND PREOPERATIONAL YEARS .	11-113

11.0 FINFISH OF NEW HAVEN HARBOR

by David N. Pease, Neil B. Savage and Christopher J. Schmitt
Normandeau Associates, Inc., Bedford, N. H.

INTRODUCTION

Although severely polluted, New Haven Harbor supports a diverse and productive ichthyofauna. The harbor provides habitat for many commercially, recreationally and ecologically important fishes. As with most mid-Atlantic estuaries, New Haven Harbor is important as a nursery area both for species that spawn locally and for others that spawn in Long Island Sound and further offshore on the continental shelf. The harbor also has importance as a feeding ground for adults of some species.

Prior to April 1970, when The United Illuminating Company commenced ecological studies in the harbor, no long-term or comprehensive study of finfish in New Haven Harbor had been made. United Illuminating monitoring studies have been conducted continuously since 1971 to provide both baseline and operational data as a means of assessing potential impacts of New Haven Harbor Station operation on this valuable resource. The results of these investigations have been presented and interpreted regularly in a series of Annual Reports (NAI, 1973, 1974a, 1974b, 1975a, 1975c, 1976a, 1977a, 1978a). This report provides a comprehensive account of the New Haven Harbor ichthyofauna, discusses the potential for impact of New Haven Harbor Station operations on 16 representative finfish species, and evaluates the magnitude of impacts that have been detected.

Review of Comparable Studies

Mill River Studies

An unpublished student paper (Bissel, 1971) and an FWPCA (1970) survey describing some fishes in the Mill River below the Whitney

Dam were reviewed. During April and May 1974, NAI conducted a series of investigations in the Mill and Quinnipiac Rivers and the Grand Avenue Reach of New Haven Harbor for United Illuminating (NAI, 1974c). Fishes were sampled each month with two types of seines and with gill nets. Both seines and gill nets were dissimilar to those used in the New Haven Harbor Station Ecological Monitoring Studies (NHHSEMS). Ichthyoplankton were also sampled using a 1 meter, 505 μ m mesh net.

Studies for the City of New Haven

Gill nets were fished in the West River area of New Haven Harbor during July and August 1974 as part of a study conducted for the City of New Haven by NAI (1975b). These nets, also unlike NHHSEMS nets in dimensions and construction, were fished overnight at four locations.

Pre-1971 New Haven Harbor Station Studies

Prior to commencement of the NHHSEMS in 1971, monthly otter trawling (16 ft, semiballoon) was conducted by Raytheon Company (1971) at locations roughly equivalent to NHHSEMS Stations 3, 4, 5, 8, 11 and 13 from June through November 1970. Beach seining (50 ft x 6 ft, 1/4 in. square mesh) was also conducted monthly from June through November, at Morris Cove, Fort Hale, the Harbor Station site, and on the north and south sides of Sandy Point.

Published Studies of the New Haven Harbor Ichthyofauna

The only published investigation of New Haven Harbor fishes to date is that of Warfel and Merriman (1944). These authors reported the results of a year-long seining program conducted at Morris Cove. Although a Morris Cove seine station was also included in the NHHSEMS, direct comparisons with these historical data are limited because of differ-

ences in sampling methods. Warfel and Merriman (1944) used a 30-ft x 4-ft minnow seine fished in multiple (3-6) hauls of variable duration.

Contemporaneous Power Plant Studies, Greater Long Island Sound

Baseline and/or monitoring studies have been conducted by various investigators at other Long Island Sound power-plant sites concurrently with Harbor Station investigations. Results of these investigations have been incorporated into this report to separate trends specific to New Haven Harbor from variability observed over a wider geographic area. These other data sources have also been reviewed to determine whether or not New Haven Harbor represents a special or unique fisheries resource.

Stamford Harbor, Connecticut

The Stamford program, conducted for the Northeast Utilities Service Company (NUSCO), was similar with respect to equipment and periodicity to the NHHSEMS, and ran from April 1971 through October 1973 as reported by NAI (1972; 1974d). The program called for year-round monthly otter trawling at six stations, and monthly gill netting (five stations), and seining (four stations) April through November.

Millstone Point, Connecticut

Environmental data collected in conjunction with the Millstone Point nuclear power-plant monitoring program were summarized by the Northeast Utilities Service Company (NUSCO, 1976). Millstone finfish sampling involved otter trawling, gill netting, and seining at various locations from April 1969 through December 1976. Some of the equipment employed in these studies is comparable to that of the NHHSEMS, but the Millstone program was altered in scope and periodicity several times between 1969 and 1977. The shore-zone fish community and its apparent

responses to the Millstone thermal discharge have been described by Hillman *et al.* (1977).

In addition to baseline and monitoring investigations, several special studies have been conducted at Millstone which provided some information useful in evaluating New Haven Harbor finfish data and the effects of Harbor Station. Larval, juvenile and adult winter flounder (*Pseudopleuronectes americanus*) studies conducted in Niantic Bay were used in evaluating some of the seasonal trends observed at New Haven.

Shoreham and Northport, New York

The Long Island Lighting Company (LILCO) conducted a year-long investigation at its Northport, New York, fossil-fueled power-plant during 1972. These data were summarized in a report prepared by the New York Ocean Science Laboratory (NYOSL) (Austin *et al.*, 1973). Similar NYOSL investigations were conducted for LILCO during 1973 at the proposed Shoreham nuclear site (Austin and Amish, 1974). Sampling with gill nets, otter trawl, and beach seine generally occurred monthly in these investigations; however, the gear and methodologies employed were not equivalent to those of the NHHSEMS.

Additional Shoreham baseline finfish data were collected by the New York State Department of Environmental Conservation (NYSDEC) during 1971 and 1972 (Zawacki and Briggs, 1976) and by LILCO (Perlmutter, 1969; 1970; 1971). As was the case for the NYOSL studies, the gear types used in these early studies are not comparable to those employed in the NHHSEMS. Nevertheless, data from these sources illustrate trends that are compared in this report to concomitant trends in New Haven Harbor.

Impingement

Supplementary to ecological baseline and monitoring studies, utilities operating power-plants that use Greater Long Island Sound

waters for cooling have been collecting data on the quantities and sizes of impinged organisms. In addition to New Haven Harbor Station, impingement data are available from the following powerplants:

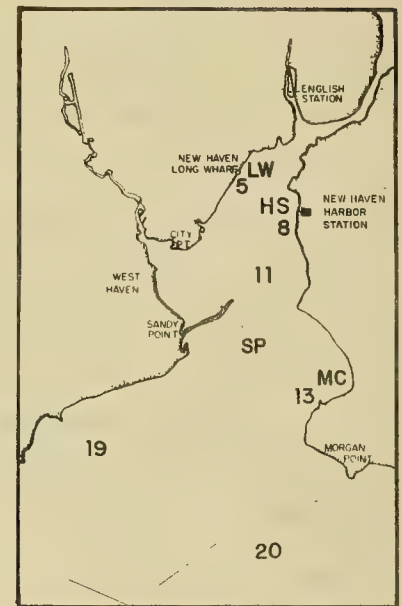
<u>UTILITY</u>	<u>PLANT</u>	<u>PERIODICITY AND DURATION</u>
UI	Bridgeport Harbor Station	Weekly, January-December 1977
NUSCO	Devon Station	Biweekly or monthly, August 1975 - August 1976
NUSCO	Middletown	Biweekly or monthly, August 1975 - August 1976
NUSCO	Norwalk	Biweekly or monthly, August 1975 - August 1976
NUSCO	Montville	Biweekly or monthly, August 1975 - August 1976
LILCO	Northport	Monthly, February - August & October and December 1972
LILCO	Port Jefferson	Monthly, January - December 1976
LILCO	Glenwood	Monthly, January - December 1976
NUSCO	Millstone Point	Daily, May 1971 - December 1977

As described for the monitoring and baseline data, these impingement data sources have been utilized to aid interpretation of occurrences observed at New Haven Harbor Station. Impingement data have been utilized both in the characterization of the Harbor, where impingement was considered as a type of sampling, and in the analysis of New Haven Harbor Station impacts.

METHODS

A monthly, harbor-wide sampling program using the following sampling methods was initiated in the spring and summer of 1971, and continued through October 1977 (Figure 11-1).

Finfish Sampling Stations



		1971	1972	1973	1974
		J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
GILL NETS	5				
	8	x x x x x	x x		x x x
	13	x x x x x	x x x x x x x x	x x x x x x x	x x x x x x x
	19	x x x x x	x x x x x x x x	x x x x x x x	x x x x x x x
SEINE NETS	LW				
	MC	x x x	x x x x x x x x	x x x x x x x x	x x x x x
	HS	x x x x	x x x x x x x	x x x x x x x x	x x x x x x x x
	SP	x x x x x	x x x x x x x	x x x x x x x	x x x x x x x x
TRAWLS		J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
	5	PROGRAM NOT INITIATED	x x x x x x x x	x x x x x x x x x x	x x x x x x x x x x x x
	8	x x x x x x x x	x x x x x x x x x x	x x x x x x x x x	x x x x x x x x x x x
	13	x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x	x x x x x x x x x x x x
	19	x x x x x x x x	x x x x x x x x x x x	x x x x x x x x x x	x x x x x x x x x x x x
	20	x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x	x x x x x x x x x x x x

x = sampled, caught

o = sampled, no fish

= not sampled

		1975	1976	1977
		J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O
GILL NETS	8	x x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x x
	8A	x x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x x
	13	x x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x x
	19	x x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x x
SEINE NETS	LW	x x x x x x x x x x	x x x x x x x x	x x x x x x x
	MC	x x x x x x x x x x	x x x x x x x x	x x x x x x x
	HS	x x x x x x x x x x	x x x x x x x x	x x x x x x x
	SP	x x x x x x x x x x	x x x x x x x x	x x x x x x x
TRAWLS		J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O
	5	x x x x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x
	8	x x x x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x
	11	x x x x x	x x x x x x x x x x x x	x x x x x x x x x x
	13	x x x x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x
	19	x x x x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x
	20	x x x x x x x x x x x x	x x x x x x x x x x x x	x x x x x x x x x x

Figure 11-1. Finfish samples taken through October 1977 using gill nets, seine nets, and otter trawls (stations as indicated). New Haven Harbor Ecological Monitoring Studies, 1979.

Otter Trawl Sampling

Monthly otter trawling was conducted at Stations 5, 8, 13, 19 and 20 (Figure 11-1) from May 1971 through June 1975 to sample demersal fishes. The trawl used was a 25-ft Marinovich semiballoon otter trawl, with a 1-3/8-in. square mesh body and a 1/4-in. square mesh cod-end liner. Station 11 was added in July 1975 to provide additional information from the center Harbor area, close to the site of Harbor Station (Figure 11-1), during start-up and subsequent operational periods. At that time, the program was also changed to incorporate paired ten-minute tows at each station instead of the previously employed single ten-minute tow (see Section 8.0). Within the study period delineated above, April 1973 and January 1977 were the only months during which trawl sampling was not conducted (Figure 11-1).

Gill Net Sampling

Monthly gill netting to sample pelagic fishes commenced in June 1971 and was initially carried out only during the warmer months at Stations 5, 8, 13 and 19. The gill nets, 150-ft long and 6-ft deep, were composed of six 25-ft panels of 3/4, 1, 1-1/4, 1-1/2, 2 and 2-1/2 inch square mesh nylon. All nets were fished overnight at approximately 2-1/2 ft above bottom.

During April 1975, the gill net program was modified to 1) substitute Station 8A, across the channel from the Harbor Station discharge for Station 5, and 2) operate year-round to gain information on the distribution and abundance of Atlantic herring (*Clupea harengus*), a winter migrant species. Limited gill net data were collected during January 1977 due to the presence of ice throughout much of the Harbor.

Shore-Zone Seining

Seining for shore-zone fishes was conducted monthly from April through November at four New Haven Harbor locations: Long Wharf, Morris Cove, Harbor Station, and Sandy Point (Figure 11-1). There were no April collections for either 1971 or 1973, and only the Long Wharf site was sampled in April 1972 (Figure 11-1). A 100 ft x 6 ft, 1/4-in square mesh, beach seine was used throughout the program, sampling approximately 10,000 ft² per haul.

Monitoring of Impingement

United Illuminating Company personnel have regularly sampled the fishes and other marine life impinged on the plant's travelling screens since the start-up of the New Haven Harbor Station cooling system pumps in July 1975. One 24-hr catch of impinged fishes was identified, enumerated and measured each week by trained UI personnel.

Ichthyoplankton

Methods for collection of ichthyoplankton are presented in Section 4.3.

Processing of Specimens

Finfish captured in the otter trawl, gill net and seine sampling programs were identified, enumerated, and measured (to the nearest mm total length) in the field whenever possible. For otter trawl specimens, only those captured in the first tow of a pair were measured; specimens in the second tow were identified and enumerated only. When samples contained numerous individuals of the same species, a random sample of 25-50 individuals was measured; the rest were enumerated. Total weight of each species in each sample was also determined in the

field. Selected specimens of both known and unknown species were preserved and returned to the laboratory to confirm identification. The primary reference for identifications was "Fishes of the Gulf of Maine" (Bigelow and Schroeder, 1953); other general keys available to use were Breder and Nichols, 1926; Hildebrand and Schroeder, 1928; and Thomson, Weed and Taruski, 1971. All remaining live specimens were released.

CHARACTERIZATION OF NEW HAVEN HARBOR ICHTHYOFAUNA

In the following discussion, the components of the New Haven Harbor finfish assemblage are first identified and described in terms of: 1) frequency with which species occur in the collections, 2) seasonal trends in species composition, and 3) general understanding of species habits as they pertain to movements into and within New Haven Harbor. This community-level discussion is followed by a more detailed analysis of the distribution and movements of 16 representative species selected on the basis of: 1) frequency of capture of one or more life stages, 2) ecological and economic importance, and 3) the nature and extent of their utilization of New Haven Harbor (Table 11-1). In the final analysis, particular emphasis is placed on the situation presented by the operation of New Haven Harbor Station in light of preexisting deteriorated environmental conditions in New Haven Harbor.

Distribution of New Haven Harbor Ichthyofauna

Despite intensive, consistent and quantitative sampling, and a voluminous data base, no population estimates are made in this study. Finfish populations were rarely uniformly distributed in space or time; many of the species important in New Haven Harbor were schooling fishes, and thus were either absent or abundant in samples depending on random chance or fish behavior. Other species were either too large and powerful or too small to be effectively sampled at all at important life-history stages by the methods employed. For these and other rea-

TABLE 11-1. RATIONALE FOR SELECTION OF NEW HAVEN FINFISH SPECIES ADDRESSED INDIVIDUALLY.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

S P E C I E S	1				2				3				4				5				C O M M E N T S	
	a	b	c	d	a	b	c	d	e	a	b	c	d	a	b	c	d					
Winter flounder (<i>Pseudopleuronectes americanus</i>)	*	0	2	3	2	x	x	x	x					1	2	2	2	2	2	3	0	* Demersal eggs.
Winduppane (<i>Scophthalmus aquosus</i>)		2	2	3	3				x	*				2	2	2	1	1	2	3	0	* Preys heavily on epibenthic crustaceans.
Atlantic herring (<i>Clupea harengus</i>)	*	0	1	2	2		x			x			x	0	2	1	0	2	2	3	1	* Demersal eggs.
Alewife (<i>Alosa pseudoharengus</i>)	*	0	0	2	2			x		x			x	0	0	1	2	2	1	2	1	* Demersal eggs spawned in fresh water.
Blueback herring (<i>Alosa aestivalis</i>)	*	0	1	3	2			x		x			x	1	1	1	2	2	2	2	1	* Demersal eggs, most spawned in fresh water.
American shad (<i>Alosa sapidissima</i>)		0	0	1	1	x	x	x		x			x	0	0	0	0	2	1	2	1	* Rarely encountered; important in the Connecticut River and in Long Island Sound.
Atlantic menhaden (<i>Brevoortia tyrannus</i>)		2	3	3	3			x	x				x	0	1	2	1	2	3	3	1	Chronic mass mortalities.
Scup (<i>Stenotomus chrysops</i>)		0	1	2	2	x	x			x			x	0	1	1	0	2	1	2	0	Not abundant since 1973; Atlantic stocks depleted
Weakfish (<i>Cynoscion regalis</i>)		0	2	3	2	x				x			x	0	2	1	1	2	1	3	1	Atlantic stocks low but increasing.
Bluefish (<i>Pomatomus saltatrix</i>)		0	0	3	2	x				x			x	0	2	1	1	2	2	2	1	Potential attraction to thermal discharge.
Rainbow smelt (<i>Osmerus mordax</i>)		0	0	2	2	x	x	x		x			x	0	1	1	2	1	1	2	1	Not abundant since 1972.
Bay anchovy (<i>Anchoa mitchilli</i>)		3	3	3	3			x	x	x			x	2	2	2	1	0	2	3	1	Seasonally most abundant species in Harbor.
Striped bass (<i>Morone saxatilis</i>)		0	0	0	2	x			x	*			x	0	0	1	0	2	1	0	1	* Summer migrant predator in New Haven, anadromous elsewhere. Potential attraction to thermal discharge.
Atlantic mackerel (<i>Scomber scombrus</i>)		1	0	0	2	x	x	x		x				1	0	1	0	2	0	1	1	Atlantic stocks depleted.
Cunner (<i>Tautoglabrus adspersus</i>)		3	3	3	3					x				2	2	1	0	2	0	3	0	Preys heavily on molluscs and other benthic animals.
Summer flounder (<i>Paralichthys dentatus</i>)		1	1	2	2	x	x			x				0	0	1	0	1	0	2	0	Sporadically abundant.
Atlantic silversides (<i>Menidia menidia</i>)	*	*	*	3	3			x		x				2	2	2	0	0	3	2	1	*Probably completes entire life cycle in Harbor
Mummichog (<i>Fundulus heteroclitus</i>)	*	*	*	3	3			x		x				2	2	2	0	0	3	2	1	*Probably completes entire life cycle in harbor

KEY:

1. Life history stage(s) encountered and frequency:

Stage: a = eggs; b = larvae; c = juveniles; d = adults

Frequency: 0 = rarely or never encountered; 1 = occasionally encountered;

2 = regularly encountered; 3 = abundant.

2. Species' importance:

a = sport fishery; b = commercial fishery; c = forage; d = ecologically important as a significant predator on other ecosystem components;

e = anadromous species with sport fishery potential, aesthetic appeal.

3. Component of finfish community represented:

a = resident; b = summer migrant (April - October);

c = winter migrant (October - April); d = anadromous.

* Refer to Comments (6)

4. Probable type and degree of species utilization of New Haven Harbor.

Type:

a. spawning; b. nursery; c. feeding;

d. zone-of-passage.

Degree:

0 - incidental or negligible;

1 - moderate; 2 - heavy

5. Habitat utilization as reflected by successful catch methods.

a. Gill net

b. Seine

c. Trawl

d. Category:

0 - demersal

1 - pelagic

3 - regularly caught (where present)

2 - occasionally

1 - rarely

0 - never

sons, precision and accuracy of population estimates generated from this data base would be inadequate. We do not, in any case, believe that population estimates are appropriate for the highly variable assemblages of finfish characteristic of New Haven Harbor; our investigation led to a characterization of New Haven Harbor as supporting only part of the life histories that lead to the classical dynamic equilibrium of Ricker (1975) and others. It would be unreasonable to make the assumptions necessary to generate such estimates for New Haven Harbor alone. Thus, the harbor's finfish assemblages and selected species are presented in terms of relative rather than absolute abundance.

Seventy-four species of finfish were identified from New Haven Harbor samples taken from May 1971 to October 1977 (Table 11-2). Of these, none was exceptionally rare, except the sturgeon, which we believe was of Connecticut River or Hudson River origin; others which were uncommon in the collections were either species at the geographic limit of their distribution (e.g., blue runner, smallmouth flounder), non-estuarine species (e.g., haddock, pollock), or species not readily caught by the methods used (lamprey, gobies). The New Haven Harbor ichthyofauna was divided into several categories according to their occurrence in the collections. Three interrelated groups of fishes were distinguished on the basis of habitat usage as indicated by frequency of capture by each of the three methods utilized in this study and by species descriptions available in the literature. These groups are:

1. shore-zone fishes: associated with intertidal and shallow subtidal waters; captured predominantly by shore-zone seining;
2. demersal fishes: associated with the sea floor, generally bottom feeders; captured predominantly by trawls, also present in gill nets; and
3. pelagic fishes: associated with the water column, generally planktivorous or piscivorous; captured predominantly in gill nets, also present in seines and trawls.

TABLE 11-2. LIST OF FINFISH SPECIES COLLECTED IN NEW HAVEN HARBOR, APRIL 1970 THROUGH OCTOBER 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

PHYLUM: CHORDATA

Subphylum: Vertebrata

Superclass: Pisces (Finfish)

Acipenser spp.* Atlantic sturgeon
Alosa aestivalis - Blueback herring
Alosa mediocris - Hickory shad
Alosa pseudoharengus - Alewife
Alosa sapidissima - American shad
Ammodytes americanus - American sand lance
Anchoa hepsetus - Striped anchovy
Anchoa mitchilli - Bay anchovy
Anguilla rostrata - American eel
Apeltes quadracus - Fourspine stickleback
Archosargus probatocephalus - Sheepshead
Brevoortia tyrannus - Atlantic menhaden
Caranx crysos - Blue runner
Caranx hippos - Crevalle jack
Centropristes striatus - Black sea bass
Citharichthys arctifrons - Gulf stream flounder
Clupea harengus - Atlantic herring
Conger oceanicus - Conger eel
Cyclopterus lumpus - Lumpfish
Cynoscion regalis - Weak fish
Cyprinodon variegatus - Sheepshead minnow
Enchelyopus cimbrius - Fourbeard rockling
Etropus microstomus - Smallmouth Flounder
Fundulus heteroclitus - Mummichog
Fundulus majalis - Striped killifish
Gadus morhua - Atlantic cod
Gasterosteus aculeatus - Threespine stickleback
Gobiosoma ginsburgi - Seaboard goby
Leiostomus xanthurus - Spot
Limanda ferruginea - Yellowtail
Liparis spp.** - Sea snail
Melanogrammus aeglefinus - Haddock
Menidia beryllina - Tidewater silverside
Menidia menidia - Atlantic silverside
Menticirrhus saxatilis - Northern kingfish
Merluccius bilinearis - Silver hake
Microgadus tomcod - Atlantic tomcod
Micropogon undulatus - Croaker
Morone americana - White perch
Morone saxatilis - Striped bass

TABLE 11-2. (Continued)

<i>Mugil cephalus</i>	- Striped mullet
<i>Mustelus canis</i>	- Smooth dogfish
<i>Myoxocephalus aeneus</i>	- Grubby
<i>Myoxocephalus octodecemspinosus</i>	- Longhorn sculpin
<i>Osmerus mordax</i>	- Rainbow smelt
<i>Paralichthys dentatus</i>	- Summer flounder
<i>Paralichthys oblongus</i>	- Fourspot flounder
<i>Peprilus triacanthus</i>	- Butterfish
<i>Petromyzon marinus</i>	- Sea lamprey
<i>Pholis gunnellus</i>	- Rock gunnel
<i>Pollachius virens</i>	- American pollock
<i>Pomatomus saltatrix</i>	- Bluefish
<i>Prionotus carolinus</i>	- Northern searobin
<i>Prionotus evolans</i>	- Striped searobin
<i>Pseudopleuronectes americanus</i>	- Winter flounder
<i>Pungitius pungitius</i>	- Ninespine stickleback
<i>Raja erinacea</i>	- Little skate
<i>Raja ocellata</i>	- Winter skate
<i>Scomber scombrus</i>	- Atlantic mackerel
<i>Scophthalmus aquosus</i>	- Windowpane flounder
<i>Selene vomer</i>	- Lookdown
<i>Sphaeroides maculatus</i>	- Northern puffer
<i>Squalus acanthias</i>	- Spiny dogfish
<i>Stenotomus chrysops</i>	- Scup
<i>Strongylura marina</i>	- Atlantic needlefish
<i>Syngnathus fuscus</i>	- Northern pipefish
<i>Synodus foetens</i>	- Inshore lizard fish
<i>Tautoga onitis</i>	- Tautog
<i>Tautoglabrus adspersus</i>	- Cunner
<i>Trinectes maculatus</i>	- Hogchoker
<i>Urophycis chuss</i>	- Red hake
<i>Urophycis regius</i>	- Spotted hake
<i>Urophycis tenuis</i>	- White hake
<i>Vomer setapinnis</i>	- Atlantic moonfish

* Probably *A. oxyrinchus*, Atlantic sturgeon. For discussion see NAI, 1978a, Section 9.3.1.

** Larvae only; larvae of *L. liparis* and *L. americanus* cannot be distinguished.

Distributional overlap among the groups was usually related to variations in behavior patterns in differing life-history stages, although in some cases extrinsic environmental variables may have affected behavior and thus distribution. Also, some species were ubiquitous and thus defy assignment to a specific assemblage or grouping.

The characteristic and occasional component species of the assemblages associated with shore-zone, demersal and pelagic habitats on a seasonal basis are discussed below. This discussion focuses on patterns of spatial and temporal distribution observed in New Haven Harbor from April 1971 through October 1977.

Shore-zone Fishes

Numerous recent studies of shore-zone fishes of the U.S. Atlantic coast have been published, invariably utilizing seines of various characteristics. The surf-zone fishes of Fire Island, Long Island, were investigated by Schaefer (1967). Shore-zone fishes of different substrate types in Great South Bay, Long Island, were studied by Briggs and O'Connor (1971). Briggs (1975) also studied the shore-zone fishes of Fire Island Inlet, Long Island. The shore-zone fishes of Gardiner's Island, New York, were sampled and reported in Reisman and Nicol (1973). Monitoring studies for Long Island Lighting Company at their Shoreham and Northport generating stations (Perlmutter, 1969, 1970, 1971; Austin, Dickinson and Hickey, 1973; Austin and Amish, 1974; Zawacki and Briggs, 1976) included studies of shore-zone fishes. Shore-zone fishes were also surveyed at Niantic Bay for Northeast Utilities Service Company; these data are summarized in two recent reports (NUSCO, 1977; 1978). The only published historical data on the finfish of New Haven Harbor is a report on shore-zone populations (Warfel and Merriman, 1944).

The most common resident fishes of the New Haven shore zone during this study were Atlantic silversides, striped killifish, and mummichogs (Figure 11-2). Along with juvenile Atlantic menhaden which occurred frequently in the shore zone, these species comprised over 95% of all fishes seined in New Haven from May 1971 through October 1977. One or more of these species were dominant or abundant in all samplings with two exceptions. In May 1977, Atlantic herring formed a large component of the relatively small catch; and in June 1977 a small school of anchovies formed a major portion of another relatively small sampling. In general, catches were small from April to June and again in November; peaks of shore-zone fish abundance occurred in July or August. Mummichogs, killifish and silversides were dominant in April and May; mummichogs in June; silversides and killifish, July through November. Atlantic menhaden schools occurred in the shore zone most commonly July-October and most abundantly in September and October. No other species occurred consistently in the shore zone. The resulting picture of New Haven's shore-zone fish assemblage is substantially different from that described by Warfel and Merriman (1944) who, using different methods and confining their efforts to Morris Cove, found some common species to be abundant which were infrequently caught in our samples. For example, we observed relatively few pipefish, winter flounder, puffers or tomcod. Many of these differences may be largely attributable to the demise of eelgrass beds in Morris Cove during the interval between 1944 and our studies. Our results do, however, agree more with other studies using similar gear throughout the Atlantic coast (see previous citations).

Demersal Fishes

Numerous studies of demersal fish assemblages [Richards, 1963; Pearcy and Richards, 1962; and NUSCO, 1977] have been conducted in Long Island Sound. Others have studied particular demersal species (Pearcy, 1962; Moore, 1947). Three classes of demersal fish can be defined for New Haven Harbor: harbor residents, Long Island Sound residents which utilize the harbor under favorable conditions in spring and fall, and summer migrants. Two resident species, winter flounder and windowpane,

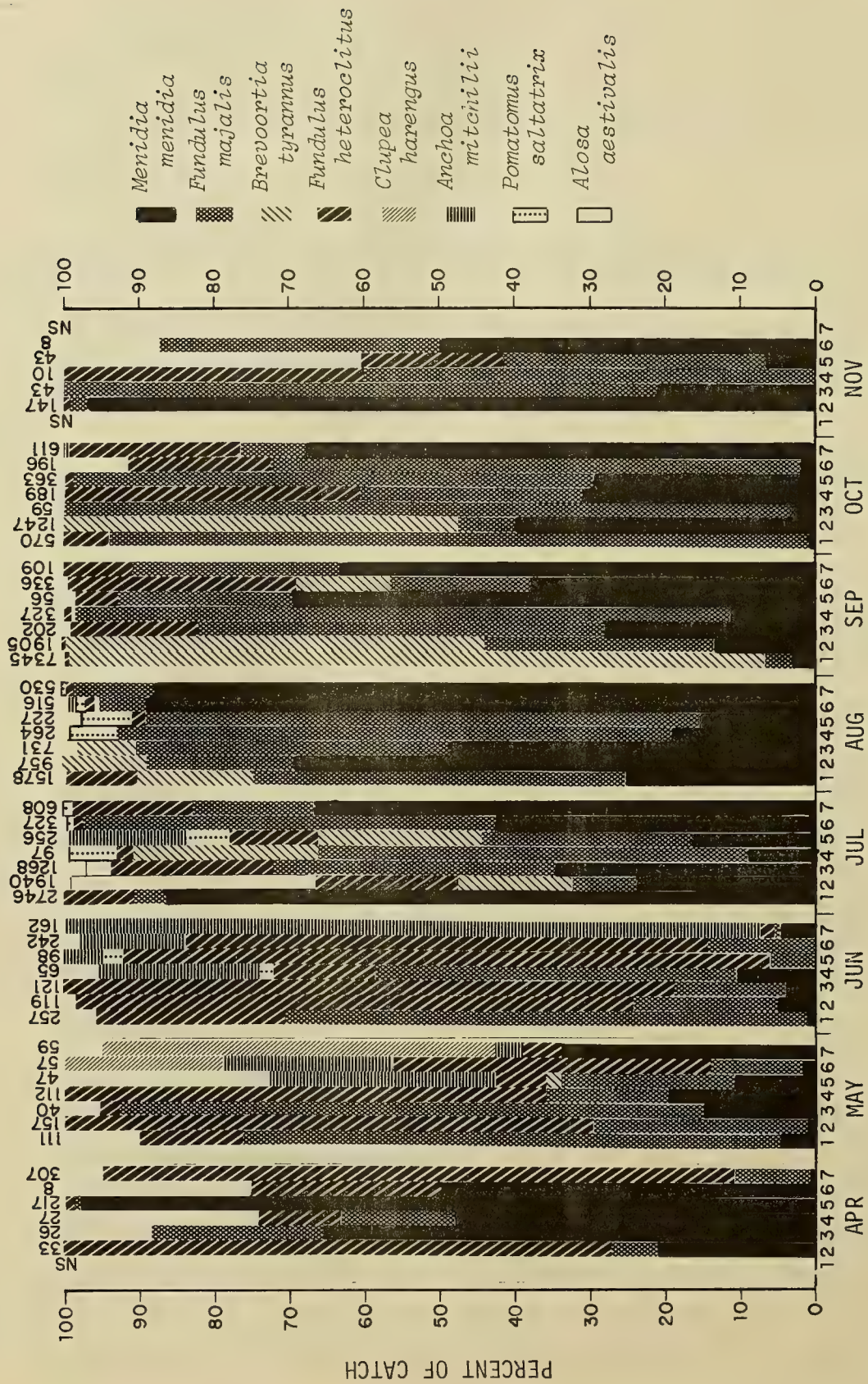


Figure 11-2. Relative abundance of dominant shore-zone fishes, April 1971 through October 1977.
New Haven Harbor Ecological Studies Summary Report, 1979.

are usually dominant. Other common resident species include cunner, pipefish, tautog, and the grubby. Long Island Sound residents which are abundant generally during May and June and October through December include hakes, silver hake, little skates, fourbeard rockling and rock gunnel. Summer migrants which frequent New Haven in abundance include scup, striped and northern searobins, and smooth dogfish. Several flatfishes which are found in New Haven in the summer months include summer flounder, hogchoker, fourspot flounder, and Gulf Stream flounder. This assemblage is similar to that described by NUSCO (1977) for the Millstone Point area, for the Mystic River estuary by Pearcy and Richards (1962), and for Long Island Sound by Richards (1963).

Overall abundance is highest during the summer nursery period and lowest in midwinter, when only the winter flounder and windowpane are active.

Pelagic Fishes

To our knowledge, there have been no studies of the pelagic fish assemblages of estuaries *per se* although many of the component species have been studied in detail. None of the pelagic species found in New Haven can be classified as "resident"; however, three categories based on the temporal distribution of the abundant species were designated. These categories are: winter migrants, of which the Atlantic herring (*Clupea harengus*) is the sole example; anadromous species which spawn in the harbor's tributaries or other Long Island Sound tributaries (striped bass, alewives, bluebacks, shad, smelt); and summer migrants, which include bluefish, weakfish, kingfish, butterfish, menhaden, bay anchovy, mackerel, and northern puffer.

Herring and smelt overwinter in the harbor and are joined by alewives and early menhaden in March and April. By the end of April, smelt remain in the harbor only as stragglers and young-of-the-year. Striped bass, butterfish, bluefish, bluebacks, shad, mackerel, and

anchovies increase in number as spring progresses. By the end of July, the mackerel, alewives, and shad have gone and northern puffers and kingfish become numerous. During this month, herring become scarce and menhaden more abundant. In September and October, young-of-the-year alewives, bluebacks, and shad arrive, followed by the herring and smelt, while kingfish depart. By the end of November, herring and smelt dominate the pelagic assemblage.

Peak abundance for this assemblage is in midsummer, when weakfish, anchovies, bluefish, and menhaden schools are most dense. As with the demersal and shore-zone assemblages, New Haven's pelagic fish are least abundant in midwinter.

Representative Species

Sixteen species representing the New Haven Harbor ichthyofauna are listed in Table 11-1, where each is ranked (where applicable) in abundance, method of capture, duration of harbor usage, commercial value, recreational value, and, most subjectively, ecological importance, which is qualified by a description of each species' usage of the estuary when mature. No shore-zone dominants were selected for consideration for the following reasons:

1. Only three species are collected exclusively in the shore zone: silversides, mummichogs and killifish.
2. Each of these species is very uniform in size, only adults and large juveniles are captured, and variability in abundance (as indicated by the sampling methods employed) is extremely high.
3. Each of the species is tolerant of wide ranges of environmental conditions including temperature, salinity, dissolved oxygen and pollutants.

4. Therefore, no information relevant to defining impact of NHHS was anticipated from further detailed review of these species' occurrences in New Haven.

Of the 16 selected species, five are categorized as demersal and 11 as pelagic on the basis of habits as described by Bigelow and Schroeder (1953). Several of the pelagic species were more readily captured in trawls than gill nets (Table 11-1) due to their relatively small size at the age-class most abundant in New Haven.

The following discussions deal with each of the 16 species separately in terms of 1) importance, 2) distribution, 3) abundance, and 4) comparison of New Haven with other Long Island Sound study sites.

Winter Flounder (Pseudopleuronectes americanus)

The winter flounder is abundant in Long Island Sound and its estuaries. Although this species ranges from Newfoundland to Georgia, it is most abundant (and sought for recreation and commercial sale) along the southern New England Coast (Bigelow and Schroeder, 1953).

The winter flounder has long been an important commercial species, particularly with the advent of motor trawlers around the turn of the twentieth century (Perlmutter, 1947). Giron (1972) identified winter flounder catch as the second most valuable landed in New Haven during 1970; baitfish was the most valuable. Lobell (1939) and Perlmutter (1940) studied the fishery in New York waters. Merriman and Warfel (1944) described the winter flounder as the primary object of the Connecticut trawl fishery in Block Island Sound. Briggs (1965) described the sport fishery for winter flounder in various bays along the south shore of Long Island, and estimated an average of 200,000 angler-days per year, with annual sport catches reaching 2.5 million fish.

Perlmutter (1947) and Poole (1966) noted that young winter flounder tend to remain in very shallow subtidal and intertidal zones and in small coves, while the larger fish are more common in deeper

water. Wells, Steele and Tyler (1973) and Kennedy and Steele (1971) observed that this species utilized shoal and intertidal areas for feeding and spawning, retreating to deeper waters as temperatures increased in midsummer. In the Weweantic River estuary in Marion, Massachusetts, Frame (1974) found that winter flounder fed in the estuary proper during the spring and near the mouth of the estuary during summer and fall. Migration is not typical of this species (Bigelow and Schroeder, 1953), although there is a general tendency for the fish to move offshore as they grow older (Perlmutter, 1947; Kennedy and Steele, 1971). Lobell (1939; cited by McCracken, 1963) described the movement of winter flounder in Long Island Sound as diffusion, in which the older individuals would travel further than the juveniles. Pierce and Howe (1977) found similarities between individual winter flounder from groups of adjacent estuarine nursery areas, but did not consider this evidence of genetic units separated by spawning behavior.

The winter flounder is omnivorous (Kennedy and Steele, 1971; Richards, 1963). Richards (1963) found more different prey species in adult *P. americanus* stomachs than in any other species in her study of the demersal fishes of Long Island Sound. Winter flounder larvae feed on copepod nauplii, copepodites, and adults; they select larger particles as they themselves grow larger. Laurence (1975) observed larval feeding and attendant growth at temperatures as low as 5°C; while adults were observed by Olla, Wicklund and Wilk (1969) to feed at temperatures between 17.2°C and 22.2°C, the full range during their observations. The winter flounder feeds only during the day, remaining quiescent on the bottom at night (Olla et al., 1969). Adult winter flounder typically feed most heavily on polychaetes (Richards, 1963; Haedrich and Haedrich, 1974; Frame, 1974; Kennedy and Steele, 1971), amphipods (Levings, 1974; Frame, 1974); bivalves (Bigelow and Schroeder, 1953; Kennedy and Steele, 1971) or fish eggs and larvae, including those of winter flounder (Kennedy and Steele, 1971). Wells, Steele and Tyler (1973) and Kennedy and Steele (1971) found that plant material occasionally makes up a significant portion of the diet. Kennedy and Steele (1971) found that winter flounder in Newfoundland cease feeding during December and January but resume feeding during the spawning period.

Winter flounder are "groundfish"; hence, it is not surprising that the most effective method for sampling both juveniles and adults has been the otter trawl (Figure 11-3). Trawl catches were relatively high during the first survey year (1971) and dropped to about half that catch in the second year (1972). Since that time there has been no substantial change in the annual catch. There have been no indications of any peculiarities of spatial distribution. Winter (January-March) and late summer (August-September) have been periods of consistently low catch (Figure 11-3). A possible explanation is temporary emigration to Long Island Sound in response to temperature conditions.

Mean length of those winter flounder caught in trawls has consistently been 6-18 cm (Figure 11-4); according to Berry *et al.* (1965) these fish belong to the O, I and II age classes. We infer from Poole (1966) and Lux (1973) that most of these fish are predominantly Age O and I individuals. Very few adult fish were commonly caught. Warfel and Merriman (1944) similarly caught few adult winter flounder while seining in Morris Cove, New Haven Harbor. Paradoxically, we caught virtually no winter flounder by seine; it is unknown whether the difference in catch between Warfel and Merriman (1944) and our study was due to differences in the fishing of the net or to a reduction in the abundance of winter flounder in the shallows. Seines fished at Millstone Point (NUSCO, 1977) also caught few winter flounder. Winter flounder were abundant in trawls taken in Long Island Sound (Richards, 1963), the Mystic River estuary (Pearcy and Richards, 1962) at Millstone Point (NUSCO, 1977) and at Shoreham, Long Island (LILCO, 1970).

Impingement of *P. americanus* at New Haven Harbor Station has been relatively high, averaging 81 individuals per day (primarily juvenile fish), or 30,000 per year (Figure 11-5). This rate of impingement is far higher than that observed at Bridgeport (UI, 1978), Montville, Norwalk Harbor, Middletown or Devon; roughly 5 to 10 times that observed at Millstone Point (NUSCO, 1977), Salem Harbor or Northport (Stupka and Sharma, 1977); and it is slightly higher than numbers impinged at Oyster Creek, Brayton Point and Mystic Station (Stupka and Sharma, 1977). This

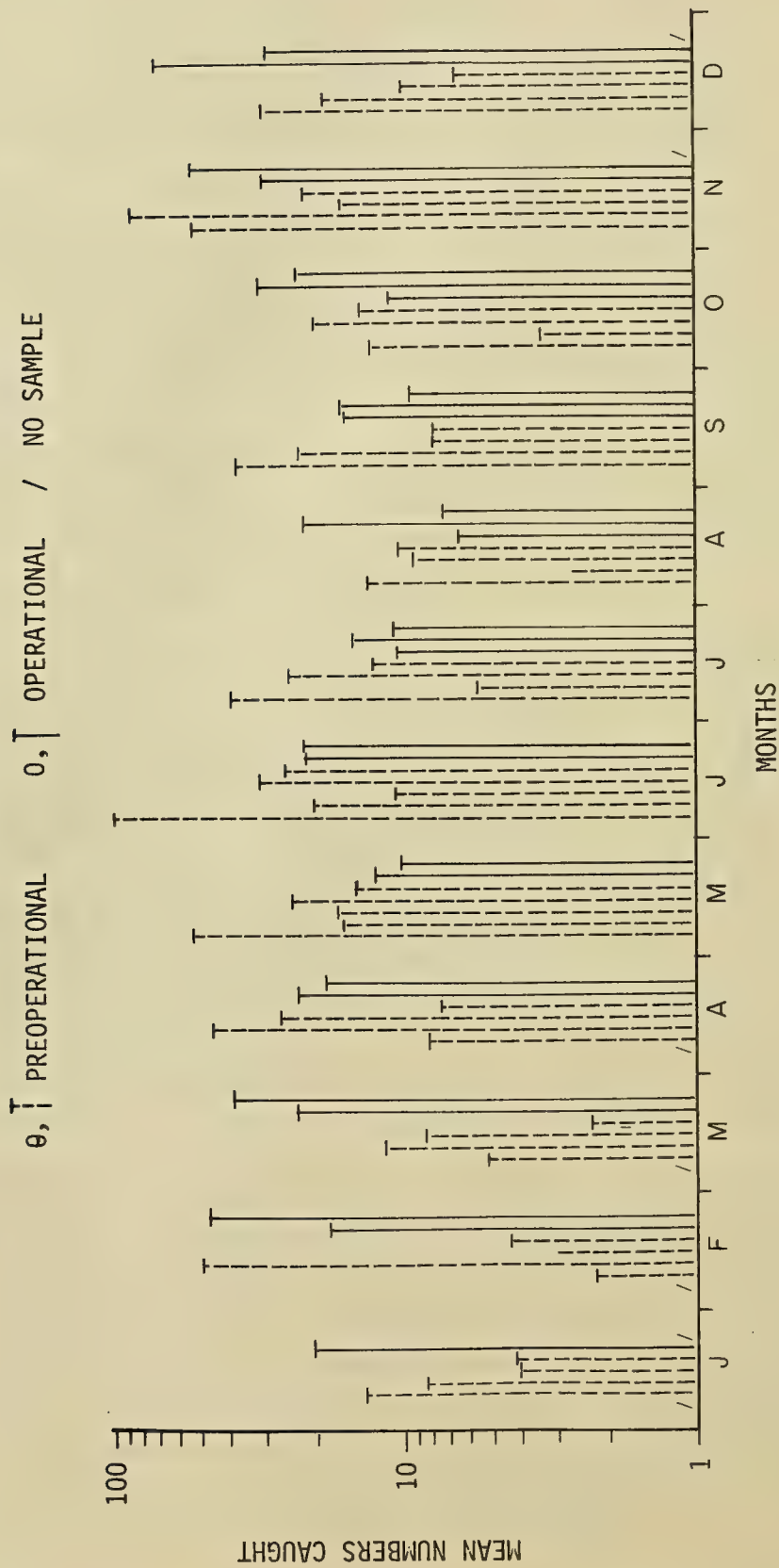


Figure 11-3. Monthly mean abundance of *Pseudopleuronectes americanus* collected by other trawl from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Pseudopleuronectes americanus

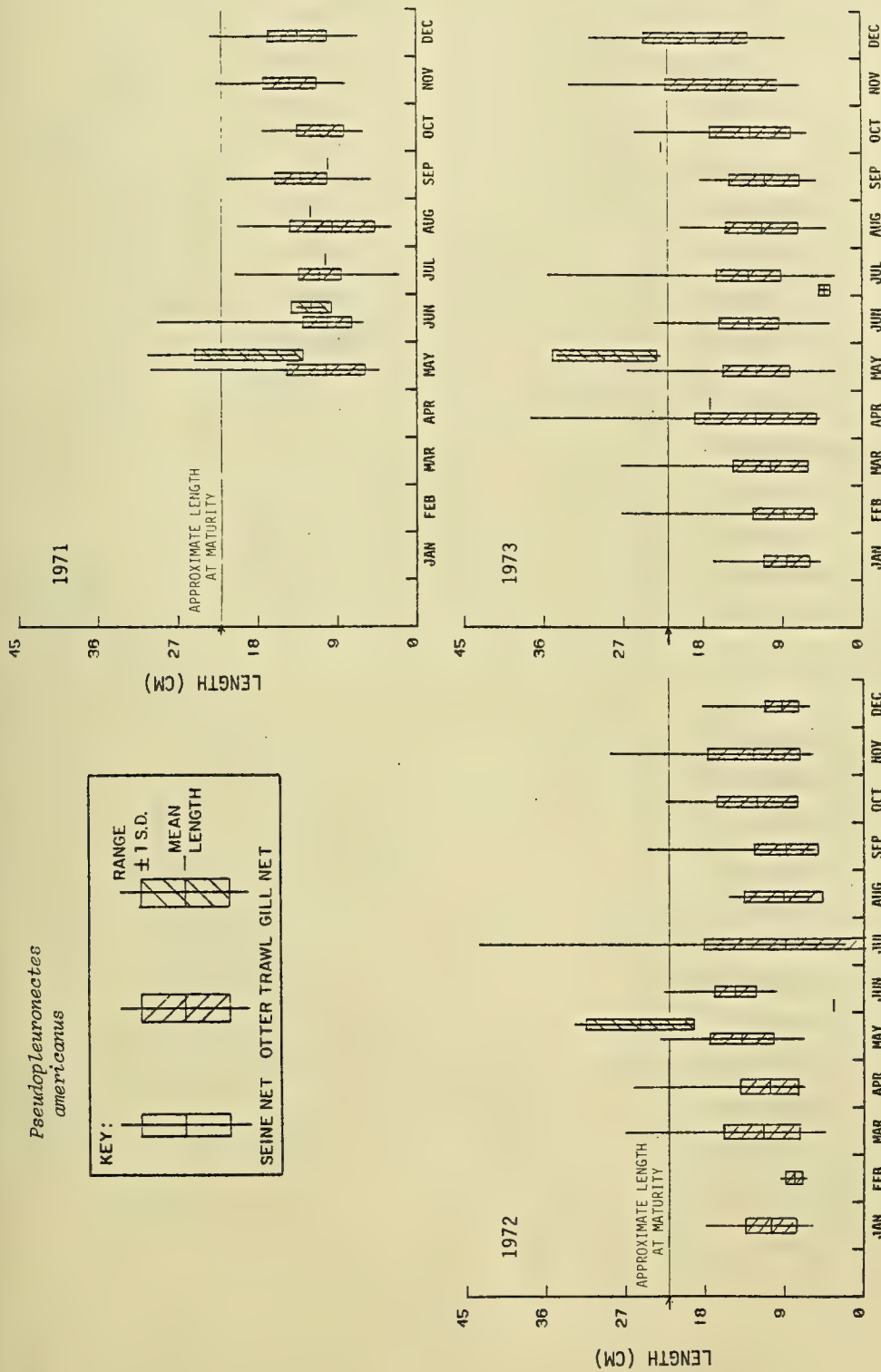


Figure 11-4. Total length (mean, range and std. dev.) of *Pseudopleuronectes americanus* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1979. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

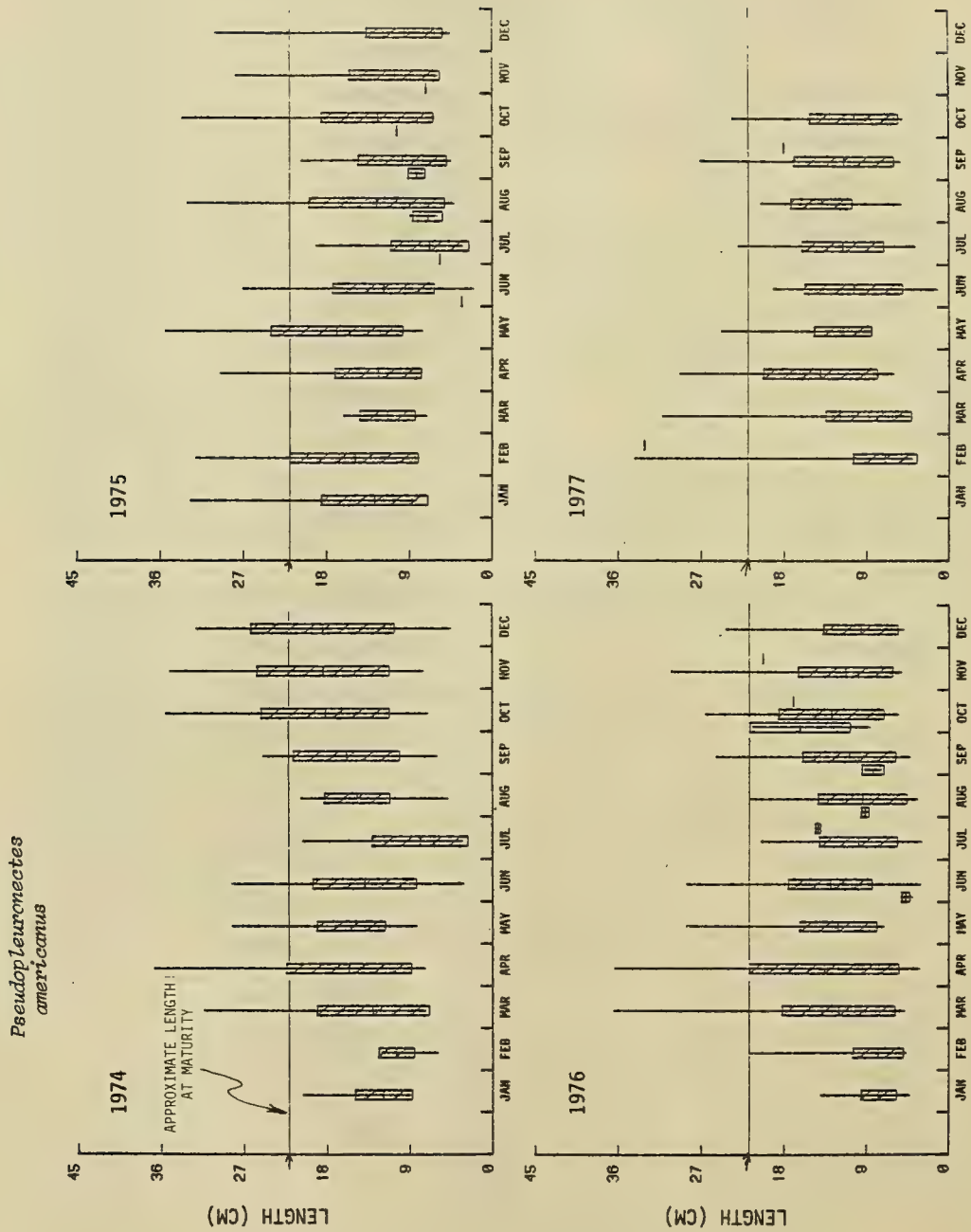


Figure 11-4. (Continued)

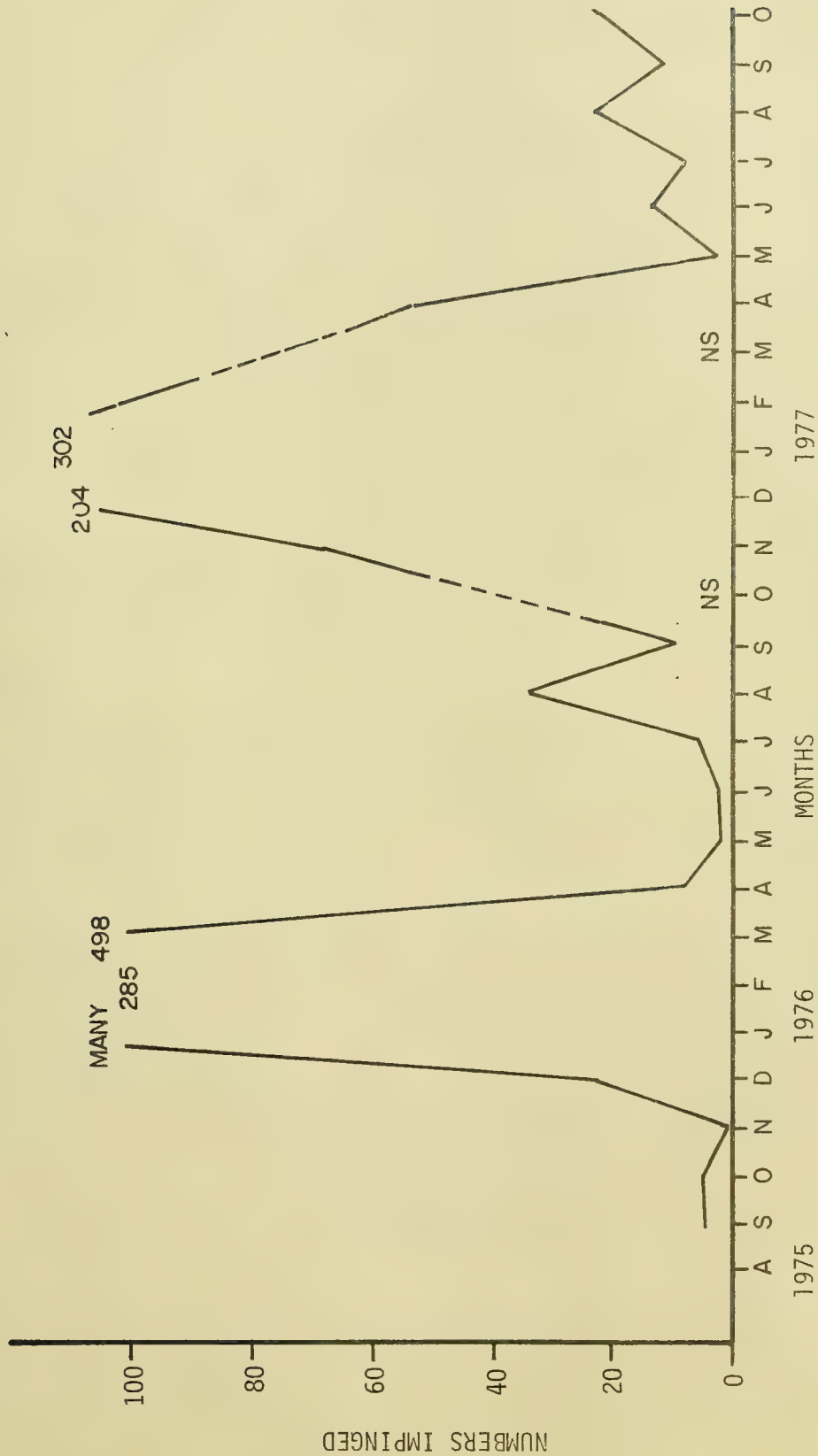


Figure 11-5. Mean daily impingement of winter flounder (*Pseudopleuronectes americanus*) by month at the New Haven Harbor Station, August 1975 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

mean rate of impingement reflects high seasonal (winter) impingement rate probably due to unusually high local abundances of winter flounder which are, because of age, behavior or physiological condition, susceptible to impingement.

According to Percy (1962), spawning activity should begin in New Haven Harbor in February and continue through April. However, ripe adults were not observed in trawl samples. The eggs are demersal, adhering to the substrate and are rarely encountered in ichthyoplankton collections. The larvae also tend to congregate near bottom and may be under represented in oblique plankton tows (Percy, 1962). NAI ichthyoplankton collections indicate larval densities ranging between 0.02 and 0.32 individuals per m^3 for the months of April and May, when the larvae have been most abundant. These data tend to support the presumed February through April spawning schedule for New Haven Harbor. Winter flounder larvae have been encountered from March through June at Millstone (NUSCO, 1977); Shoreham (LILCO, 1977), Glenwood (LILCO, 1977), Port Jefferson (LILCO, 1977), Northport (LILCO, 1977) at peak densities of 0.02-1.11 individuals per m^3 . Percy (1962) observed peak catches of winter flounder larvae during March and April ranging from 1.0 to 20.0 individuals per m^3 in the Mystic River Estuary. Wheatland (1956) observed concentrations of winter flounder larvae which ranged from 0.10 to 0.26 individuals per m^3 in Eastern Long Island Sound and from 0.03 to 0.11 per m^3 in the central Sound between late March and early June, 1952-1954. Similarly, Richards (1959) observed winter flounder larvae throughout Long Island Sound between late March and early May, 1954-1955, in concentrations of less than 1.0 per m^3 . Densities of winter flounder larvae in New Haven Harbor have been generally similar to or less than concurrent densities in Long Island Sound.

Windowpane (Scophthalmus aquosus)

The windowpane flounder is a resident of shallow water areas whose habitat preferences generally overlap those of the winter flounder.

In contrast to the winter flounder, however, the thin body of the windowpane makes filleting difficult; thus, the latter species is of little commercial importance. The principal prey items for the windowpane include mysids (especially *Neomysis americana*), sand shrimp (*Crangon septemspinosa*) and amphipods (Moore, 1947). Individuals ranging in size from 4 to 35 cm long (i.e., both juveniles and adults) were abundant in New Haven Harbor collections (Figure 11-6).

There is little evidence of seasonal onshore-offshore movements for the windowpane flounder of the type exhibited by the winter flounder (Moore, 1947). Windowpanes are apparently less migratory than the winter flounder, and are more tolerant of widely contrasting winter to summer temperature conditions that prevail in shallow embayments (Moore, 1947). Bigelow and Schroeder (1953) advanced the opinion that as a minimum requirement, summer temperatures must exceed 12°C to reach the approximate threshold above which spawning can successfully occur. This may determine the northward limit of this species' zoogeographic distribution.

Windowpanes were caught more effectively by the otter trawl than by either the gill net or beach seine. Particularly large catches were recorded for the windowpane in 1971 (Figure 11-7). Seasonal catches have usually been lowest early in the calendar year and in late summer (Figure 11-7). There is also some indication from the trawl data that catches tend to be higher towards the outer reaches of the harbor. Moore (1947) reported that Long Island Sound is a center of abundance for windowpanes. Trawl sampling at Shoreham (NYOSL, 1974) indicated a windowpane population substantially more dense than that of New Haven, while similar sampling in Niantic Bay (NUSCO, 1976) yielded population estimates less than one-half those observed in New Haven Harbor.

Windowpane are frequently found on the traveling screens of New Haven Harbor Station, but usually in relatively low numbers. The highest recorded levels of impingement occurred in January 1976 and from late November to mid December 1977, and were about 16 fish per day.

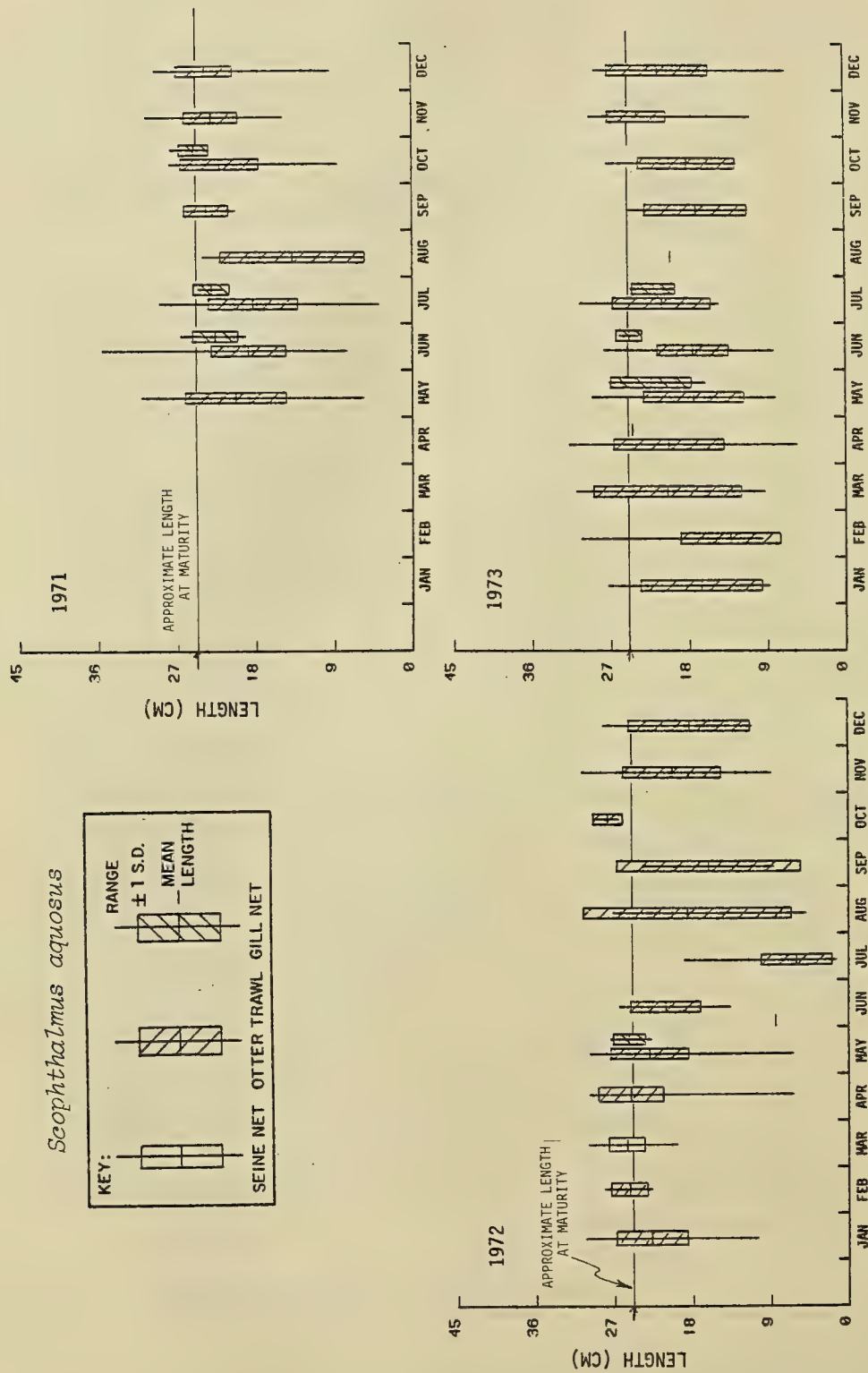


Figure 11-6. Total length (mean, range and std. dev.) of *Scophthalmus aquosus* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

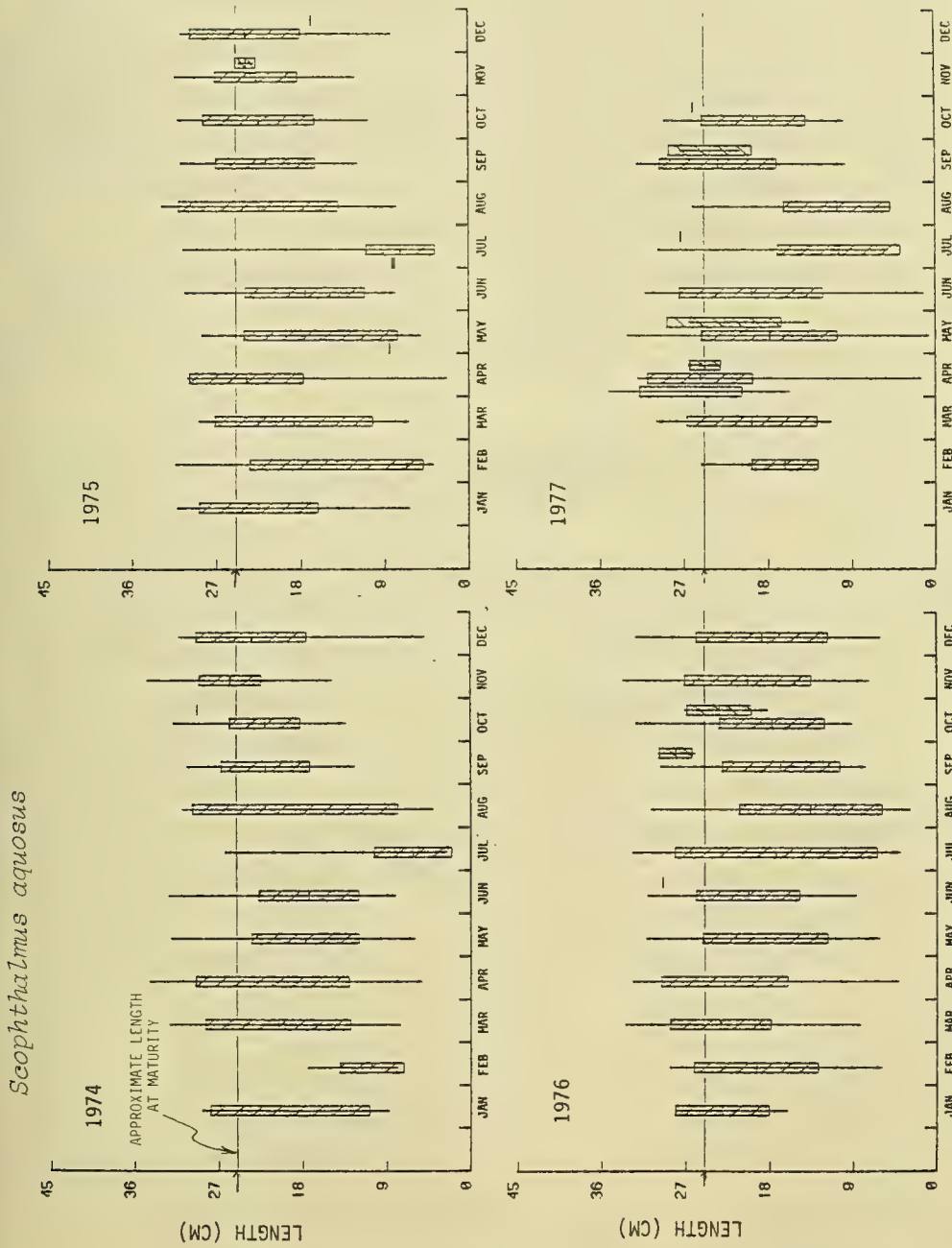


Figure 11-6. (Continued)

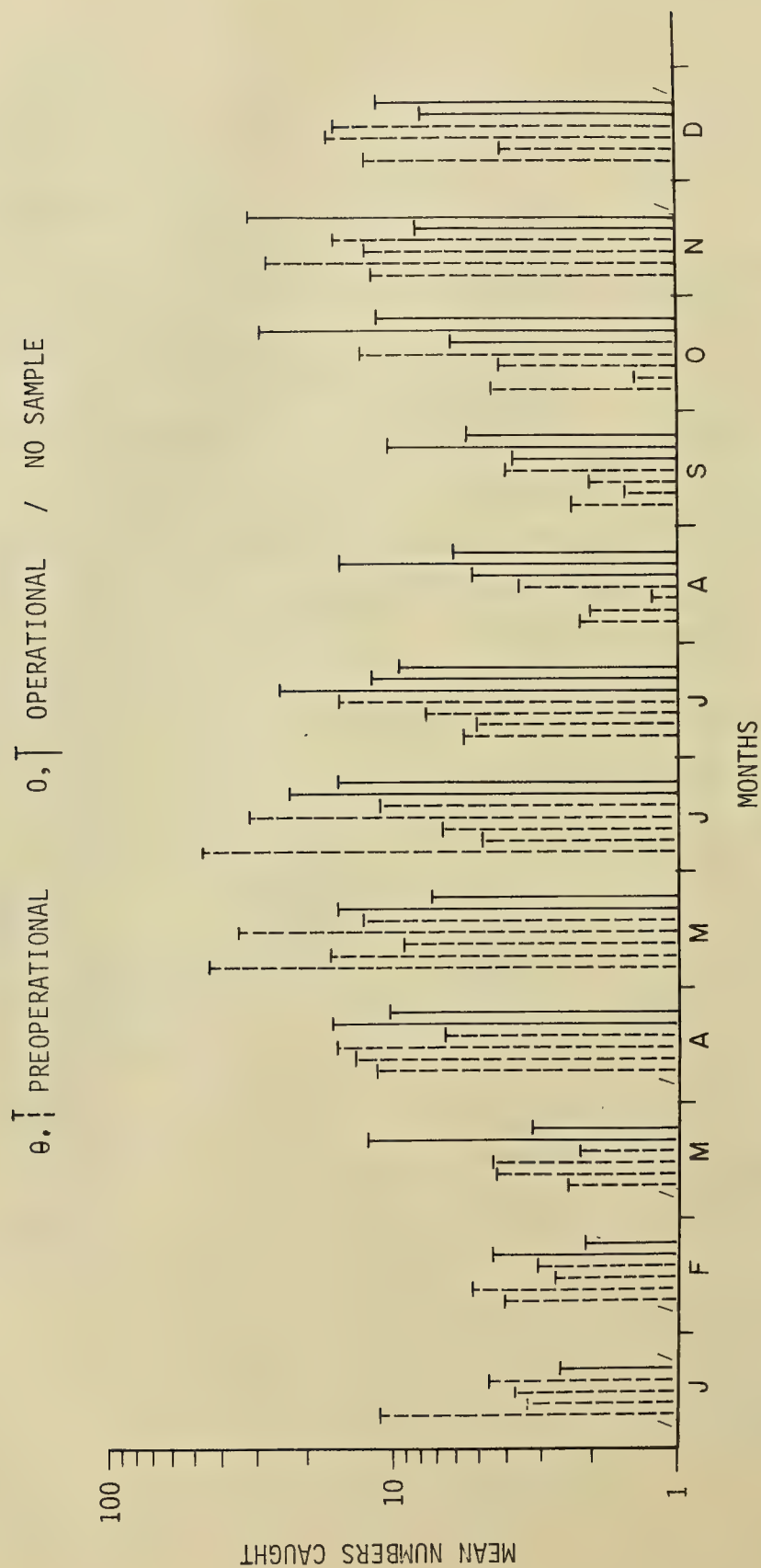


Figure 11-7. Monthly mean abundance of *Scophthalmus aquosus* collected by otter trawl from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

New Haven Harbor Station windowpane impingement levels were slightly higher than at some of the Long Island Sound power plants (Millstone [NUSCO, 1977], Shoreham [NYOSL, 1974]), but were about equal to those at Norwalk.

The ichthyoplankton collections in New Haven Harbor confirm the observations of Moore (1947), Wheatland (1956), and Richards (1959) that spawning occurs throughout the spring and early summer. The buoyant eggs have been collected at densities ranging from 0.03 to 0.28 per m^3 during May, the month of peak abundance. Peak larval densities ranging from 0.007 to 0.13 per m^3 , have occurred in June. Data from other Long Island Sound power plants indicate similar densities of eggs and larvae.

Cunner (Tautogolabrus adspersus)

Bigelow and Schroeder (1953) describe the cunner as a predominantly inshore, shallow-water, perch-like fish that is often found congregating around wharves, wrecks, floats, and aquatic vegetation (eel grass, seaweeds, etc.). Cunner feed on bivalves (particularly *Mytilus edulis*) and other benthic organisms (Olla, Bejda and Martin, 1975). They abound in sheltered settings such as those afforded by New Haven Harbor. Younger, smaller individuals tend to be found farthest into the deeper tidal creeks draining the salt marshes, and occasionally in rock pools.

Cunner are year-round residents and rarely stray far from their place of birth. They remain active until the water temperature drops below approximately 8°C, at which time they cease feeding and become dormant (Dew, 1976; Green and Farwell, 1971). The overwintering period lasts 3 or 4 months and is typically spent beneath rocks or in rock crevices; when disturbed from their repose, cunners tend to behave as if dazed and disoriented (Dew, 1976).

In New Haven Harbor Surveys, cunner (3 to 28 cm long, Figure 11-8) have been caught primarily in otter trawls and secondarily in gill nets; there are no reports of cunner being captured by beach seine. The larger catches, exceeding 20 fish per net haul, occurred during the months of May through August and prior to 1974 (Figure 11-9). Because of the habit of associating with obstructions, it is probable that this species is undersampled, and is consequently more common than these catch data indicate. Impingement rates have also been consistently low for New Haven Harbor traveling screens, never exceeding more than two fish in 24 hours; other Long Island power stations have reported impingement rates up to 10 times higher (NUSCO, 1977).

Sexual maturity is attained early in life, with most of the young-of-the-year exhibiting sexually distinct gonads by their first autumn (Dew, 1976). According to Wheatland (1956), spawning occurs from May to October; however, Dew (1976) has claimed a much shorter period of spawning activity (June to July) for Fisher's Island populations. Eggs in the NHHS study were collected from May through September. The eggs appear very similar to those of the yellowtail flounder (*Limanda ferruginea*) and are virtually identical with those of the tautog (*Tautoga onitis*). New Haven Harbor collection records did not differentiate these species, making determination of the spawning season length in New Haven Harbor problematical. Nevertheless, we believe that the Labridae-type eggs which occur in May and June (1.16 to 8.85 per m³) as well as the eggs occurring later in the year are mostly cunner or tautog, as yellowtail adults are extremely rare in New Haven Harbor, and larvae are not observed in central Long Island Sound (Richards, 1959). The density of labrid eggs was comparable to that observed in the Mystic River estuary by Percy and Richards (1963).

Cunner larvae are found in surprisingly low abundances, given the estimated egg densities; maximum larval densities (0.26 per m³) occurred in July 1974. Similarly, Richards (1959) and Percy and Richards (1963) found high egg/larvae ratios in Long Island Sound and

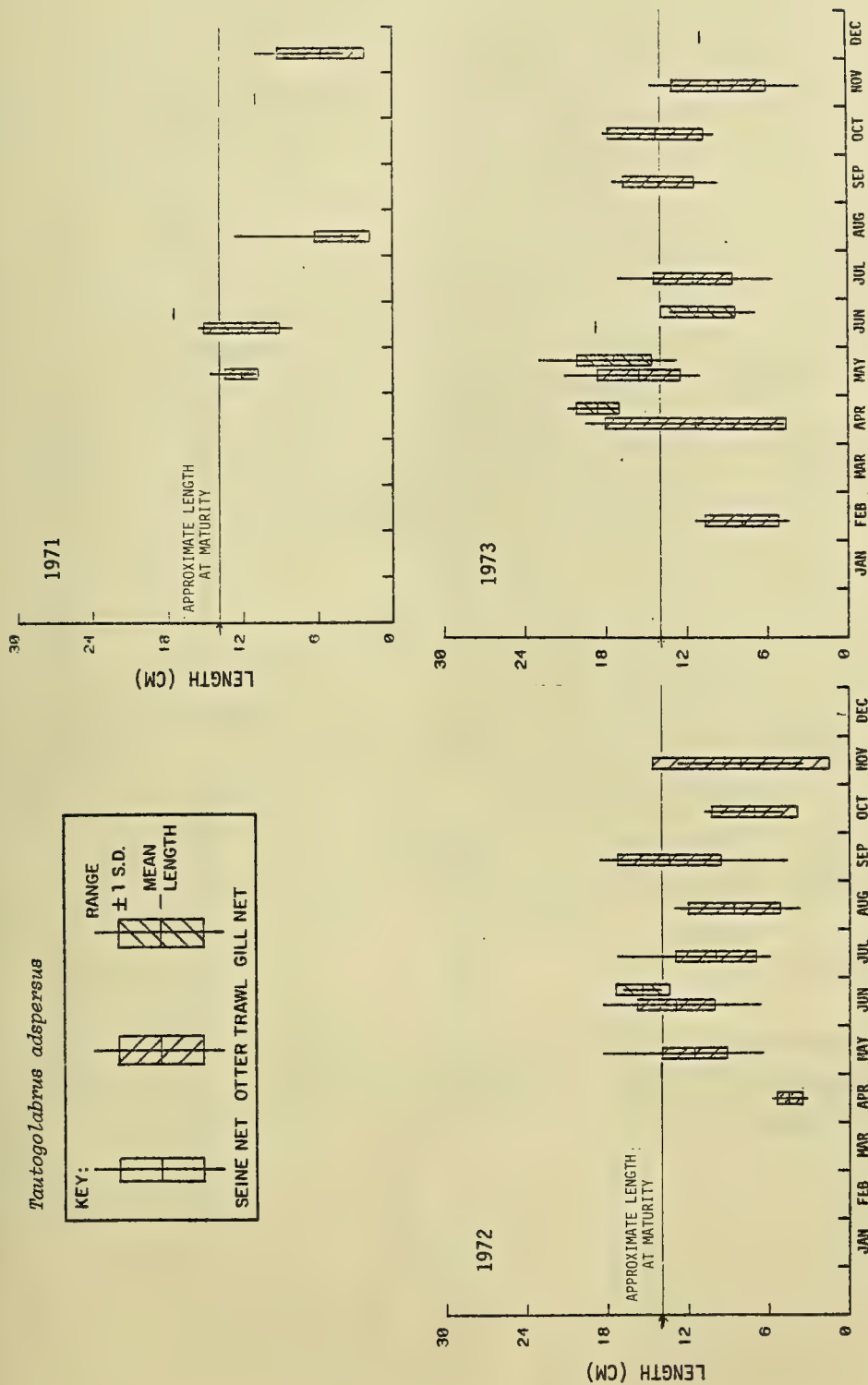


Figure 11-8. Total length (mean, range and std. dev.) of *Tautoglabrus adspersus* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

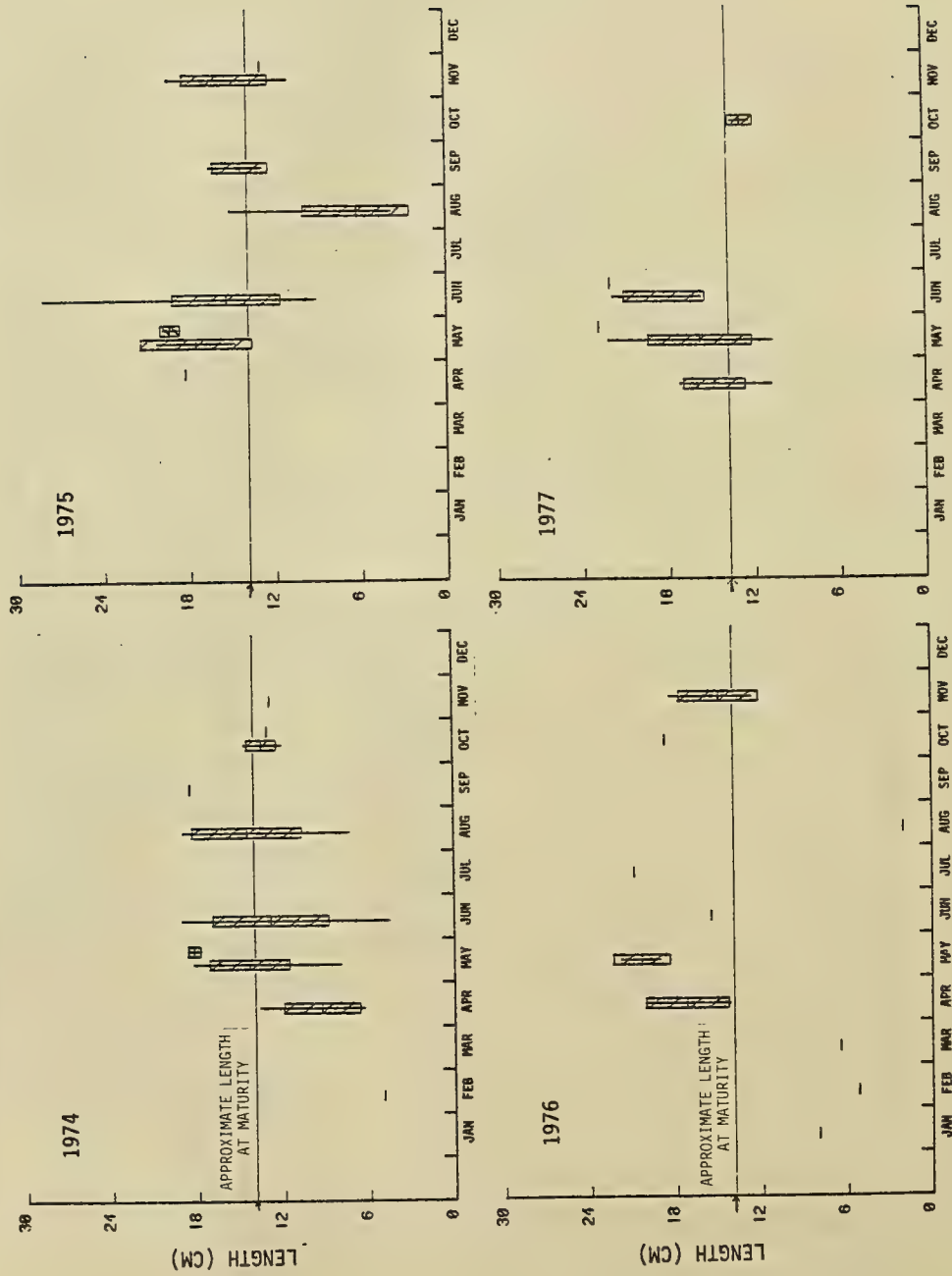
Tautoglabrus adspersus

Figure 11-8. (Continued)

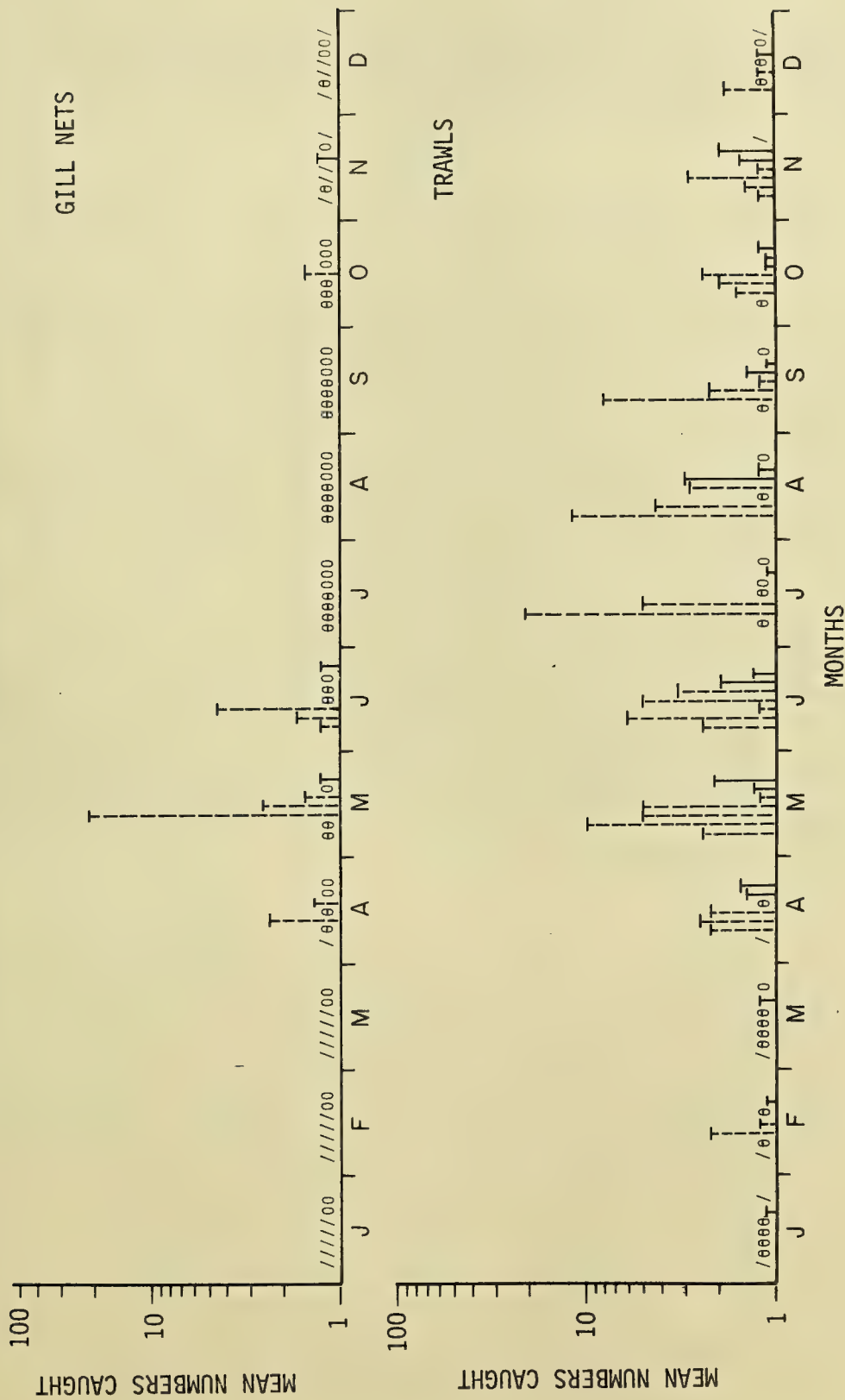


Figure 11-9. Monthly mean abundance of *Tautoglabrus adspersus* collected by trawl from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

the Mystic River estuary respectively. Studies conducted at other Long Island Sound electric generating facilities at Port Jefferson, Glenwood, Northport (LILCO, 1977) and Millstone (NUSCO, 1977) have reported comparable larval densities, but substantially higher egg densities than observed in New Haven Harbor.

Scup (Stenotomus chrysops)

Where it is found in abundance, the scup or "porgy" is the marine equivalent of the freshwater sunfish ("bluegill") in that it is a pan fish that readily takes a baited hook (Bigelow and Schroeder, 1953). Populations in the U.S. Middle Atlantic are of sufficient size to sustain a large recreational fishery as well as commercial catches which may total in the millions of pounds annually (Finkelstein, 1971). Scup annually migrate between 1) offshore wintering grounds over the New Jersey to North Carolina continental shelf and 2) inshore summering areas from Monomoy Point, Cape Cod to Chesapeake Bay (Bigelow and Schroeder, 1953). Most scup populations remain within approximately 9-10 km of the shoreline from April through October; in general, the younger fish remain close to shore (Bigelow and Schroeder, 1953). Like the winter flounder, scup are omnivorous (Richards, 1963) feeding on benthic and epibenthic organisms.

In New Haven Harbor, otter trawling, considered by Finkelstein (1971) to be the most efficient method for collecting scup, has produced the largest catches during August and September (Figure 11-10). In August 1971, several thousand young-of-the-year per tow were caught, in the outer harbor (Stations 13, 19 and 20). August 1971 was also the only occasion of moderate scup catches recorded in the inner harbor; after this date they were never captured at Stations 5 or 8. In 1972 and 1975, Station 13 yielded September catches in the hundreds; these were also primarily young-of-the-year, with a few yearlings (11 to 16 cm long) present in the 1972 catch. Adults (20 to 50 cm) were caught only occasionally, primarily in gill nets, one or two fish at a time as in August 1975 and September 1974 (Figure 11-11).

0, | PREOPERATIONAL 0, | OPERATIONAL / NO SAMPLE

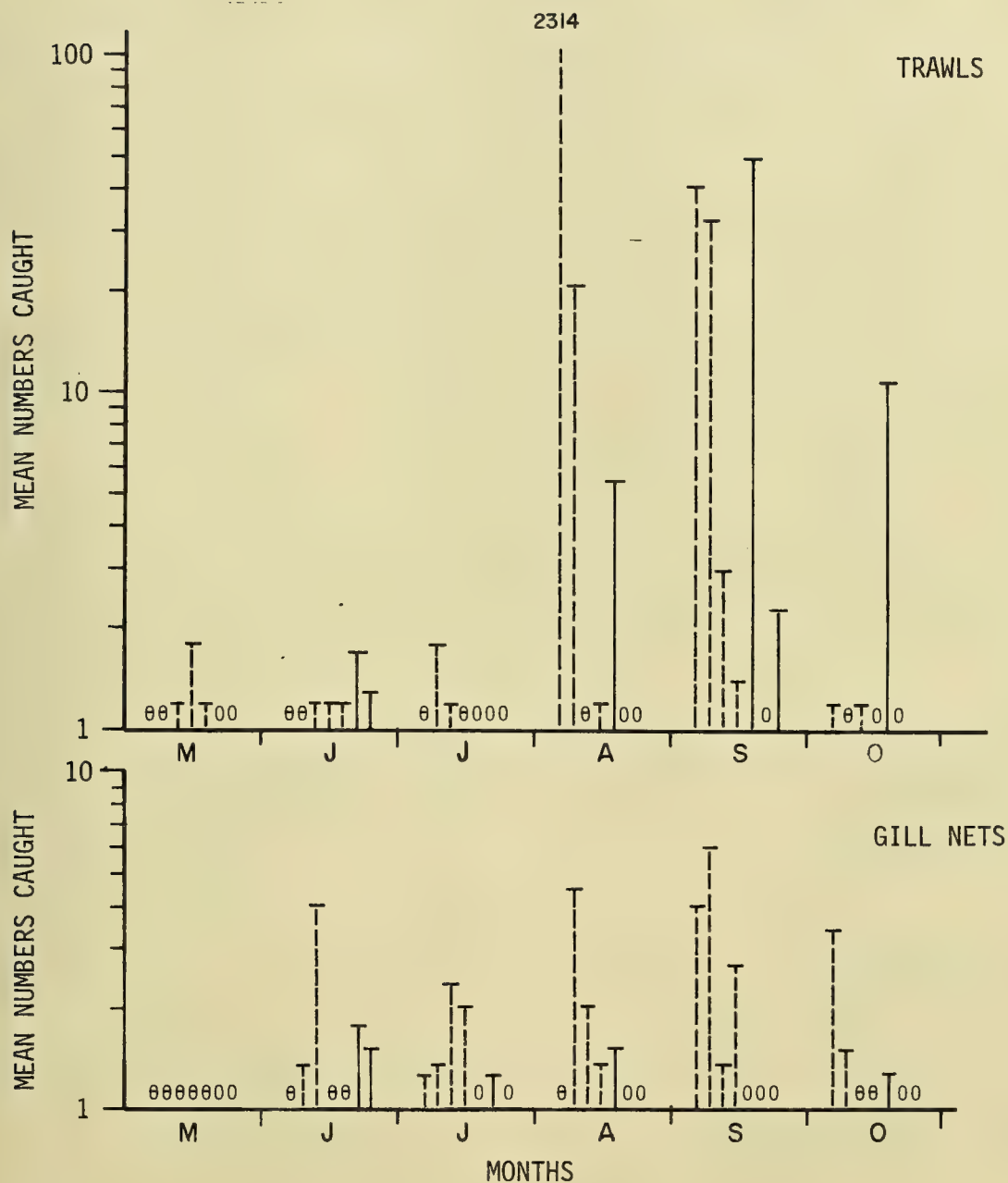


Figure 11-10. Monthly mean abundance of *Stenotomus chrysops* collected by trawl from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

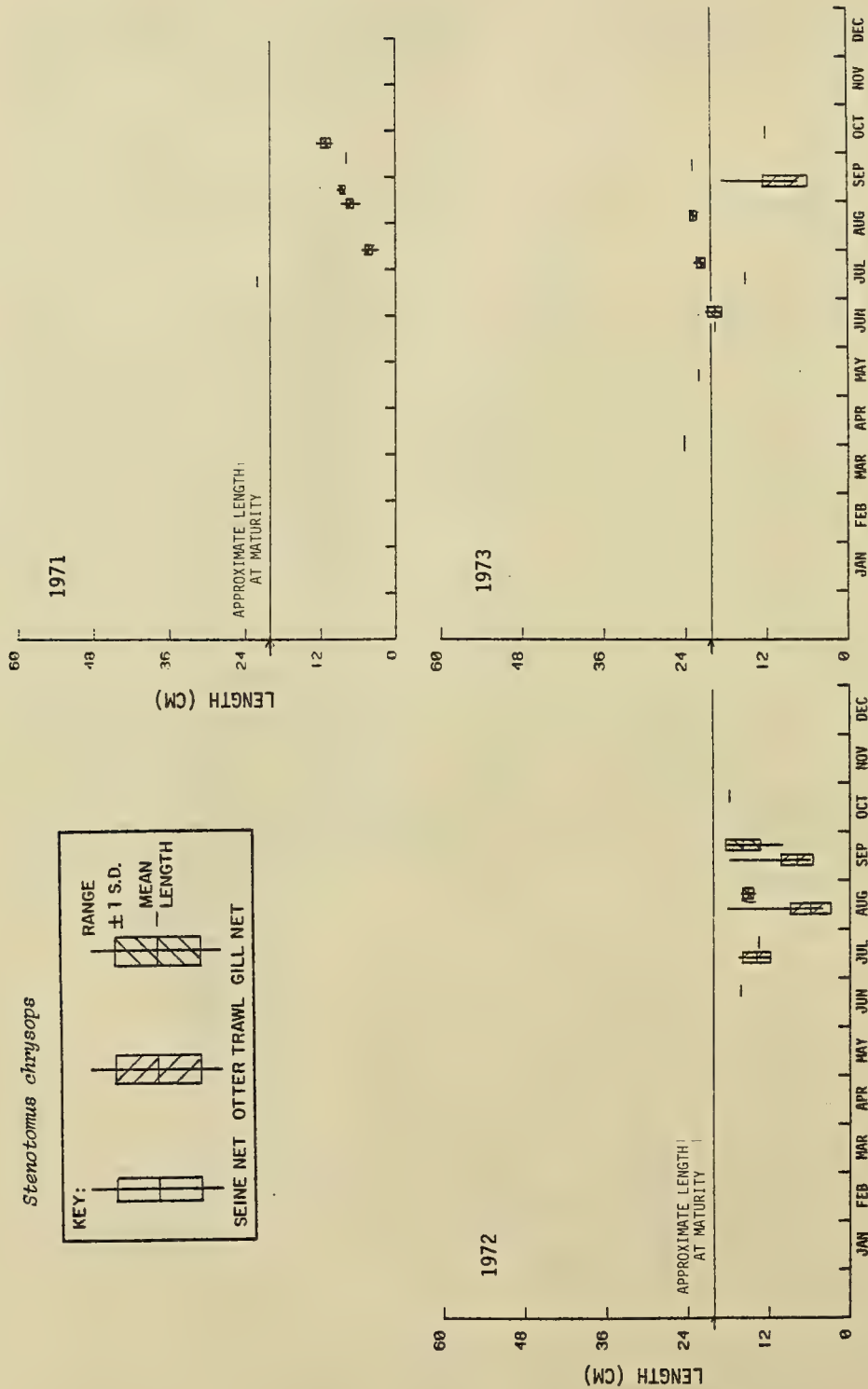


Figure 11-11. Total length (mean, range and std. dev.) of *Stenotomus chrysops* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

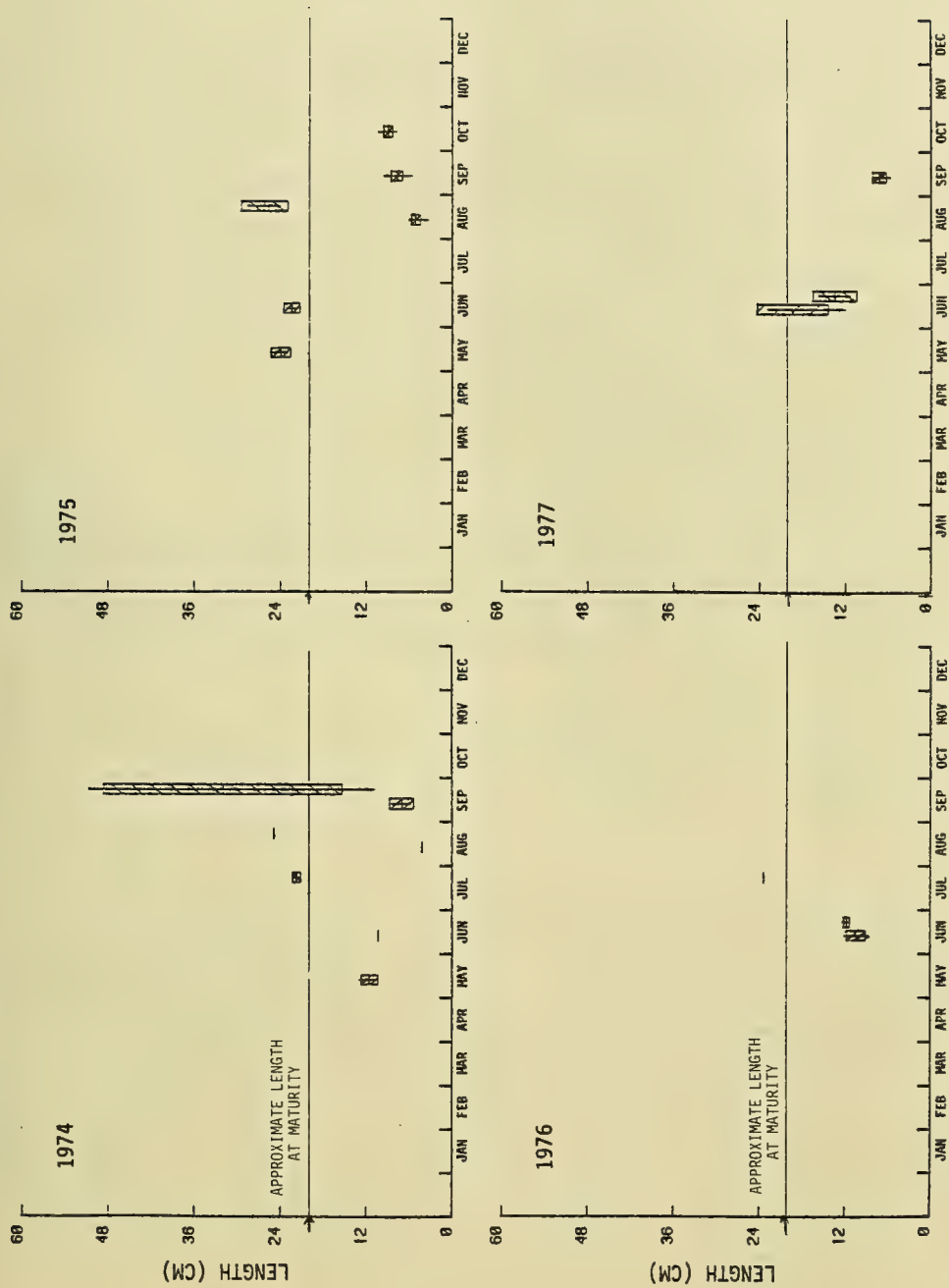
Stenotomus chrysops

Figure 11-11. (Continued)

No scup have been observed to be impinged on New Haven Harbor Station traveling screens; this correlates well with their observed scarcity in the inner harbor. Other Long Island Sound electric generating facilities (notably Millstone, NUSCO, 1977) have occasionally reported impingement of 1 to 4 individuals per day.

In southern New England, scup are reported to spawn from May to August with the maximum reproductive effort usually occurring in June (Bigelow and Schroeder, 1953). In New Haven Harbor collections, scup eggs (buoyant) have not been differentiated from those of the weakfish (*Cynoscion regalis*) and silver hake (*Merluccius bilinearis*). Peak densities of larvae identified as *S. chrysops* have been recorded for May 1975 (0.14 per m³). June 1977 was the only other occasion when these larvae were collected in New Haven Harbor (less than 0.01 per m³). Ichthyoplankton records from other Long Island Sound power plants indicated that the highest 1976 scup larval densities occurred at Millstone (approximately 0.04 per m³) in June. According to Wheatland (1956), New Haven is near the western boundary for spawning of scup in Long Island Sound; this supports the observation of low densities of eggs and larvae that were collected and the infrequency of adults.

Summer Flounder (Paralichthys dentatus)

The summer flounder, also called "fluke", is a deepwater, bottom-dwelling flatfish of substantial commercial and recreational interest (Poole, 1962; Jensen, 1971). Portions of the offshore population come close inshore during the warm half of the year, hence the origin of the common name. It is primarily the younger, smaller individuals that move well up into the harbors and estuaries of Long Island Sound. Summer flounder are predators of epibenthic and tychoplanktonic crustaceans, probably feeding on *Crangon*, *Neomysis*, and winter flounder juveniles in New Haven Harbor (Poole, 1964).

As with any groundfish, the otter trawl was the most efficient sampling device employed in the New Haven Harbor studies (Figure 11-12).

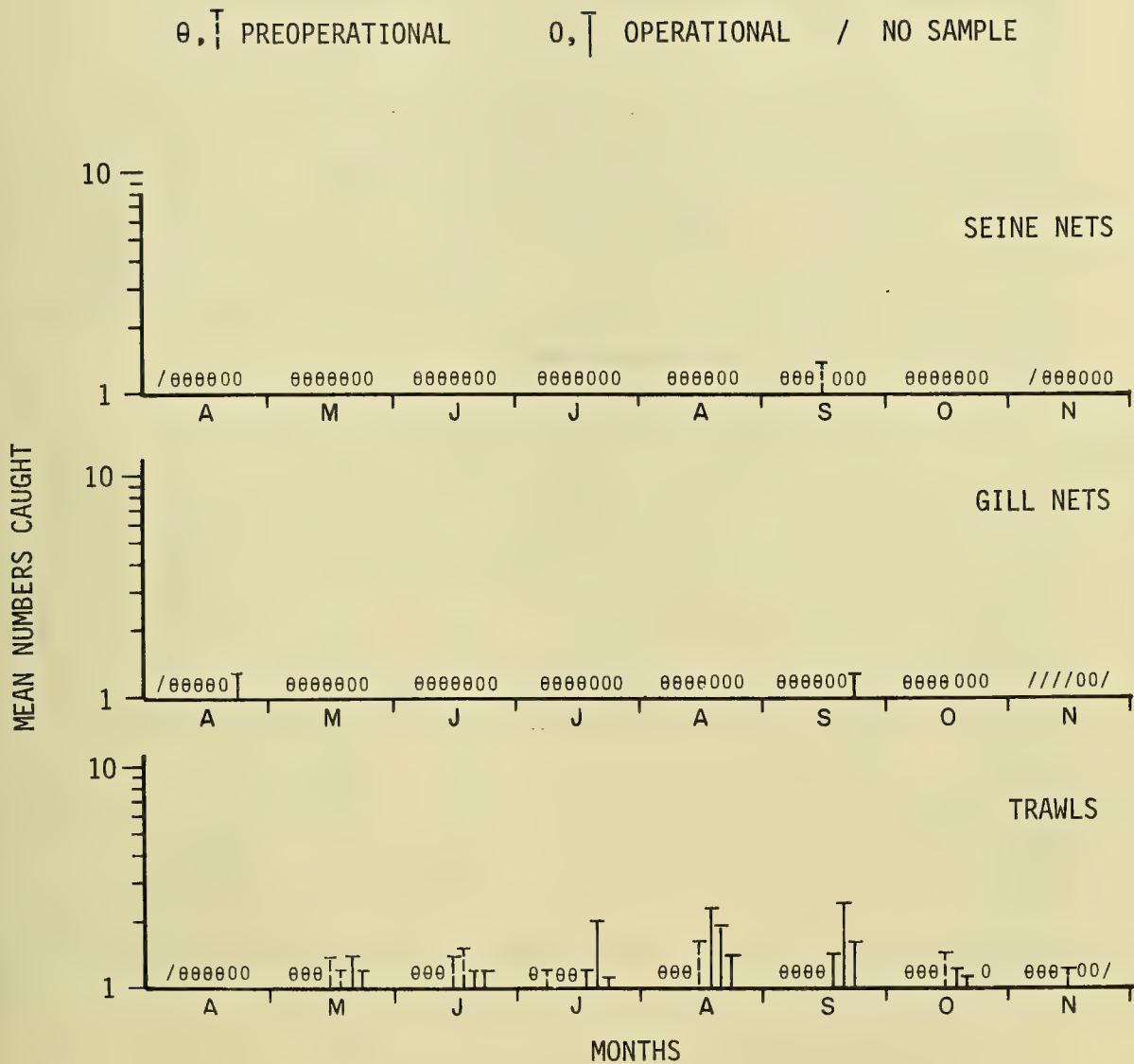


Figure 11-12. Monthly mean abundance of *Paralichthys dentatus* collected by seine, gill net and otter trawl from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Catches have been low, with the greatest catch per effort occurring in 1975 and 1976 (up to 5 fish per trawl). A few young-of-the-year (12 to 18 cm long) were taken in the fall of 1974 by both otter trawl and beach seine; otherwise, the catch has essentially been composed of adults 20 cm to 54 cm in length (Figure 11-13). Their occurrence in New Haven is limited to May through October. Prior to 1974, only one individual (34 cm long) had been caught (July 1972, by otter trawl).

With one exception, the incidence of summer flounder impingement has been very low at New Haven Harbor Station. The only time more than 10 fish have ever been recovered from the traveling screens was on the first survey date, 6 August 1975, when 61 fish were found. By contrast, impingement of summer flounder has been much more frequent at Millstone during the spring and summer.

Summer flounder spawn well offshore during the colder months; therefore, the occurrence of eggs and larvae in inshore areas are largely incidental. In New Haven Harbor, the eggs and larvae have been collected in very low densities (ranging from 0.003 to 0.001, and 0.0002 to 0.0012 per m^3 in March and April, respectively). The only other Long Island Sound power-plant study reporting the presence of summer flounder eggs and larvae has been Millstone (NUSCO, 1977), where larval densities have been comparable to those observed in New Haven Harbor. In the case of the eggs, however, the density reported for Millstone in May 1976 was a relatively high 2.5 eggs per m^3 . Wheatland (1956), Richards (1959) and Percy and Richards (1963) found no summer flounder eggs or larvae in their studies on Long Island Sound and the Mystic River estuary.

Atlantic Herring (Clupea harengus)

The herring is a transient in New Haven Harbor, regularly making brief appearances primarily during winter and spring. This species is virtually absent from the Harbor during August and September.

Paralichthys dentatus

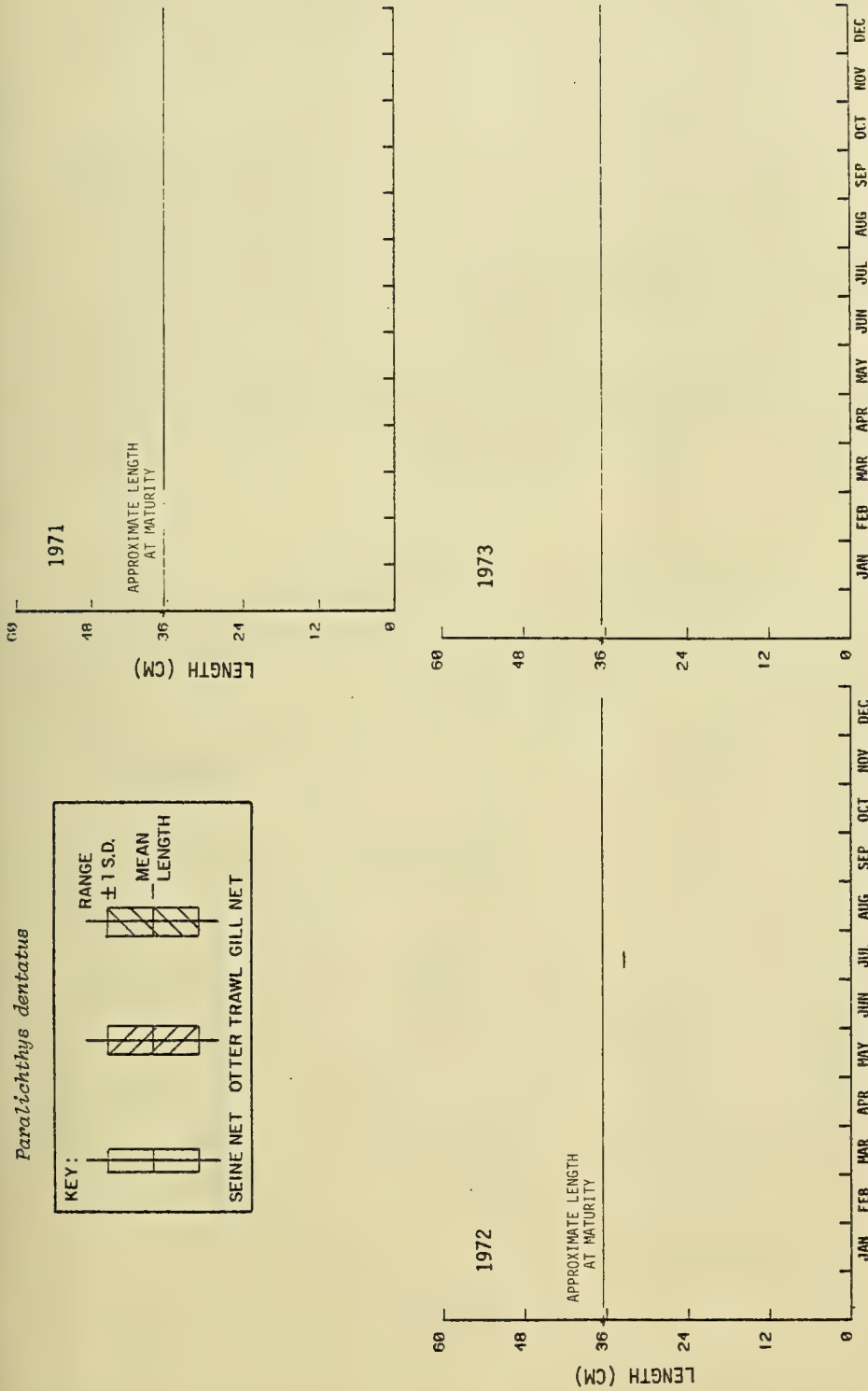


Figure 11-13. Total length (mean, range and std. dev.) of *Paralichthys dentatus* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

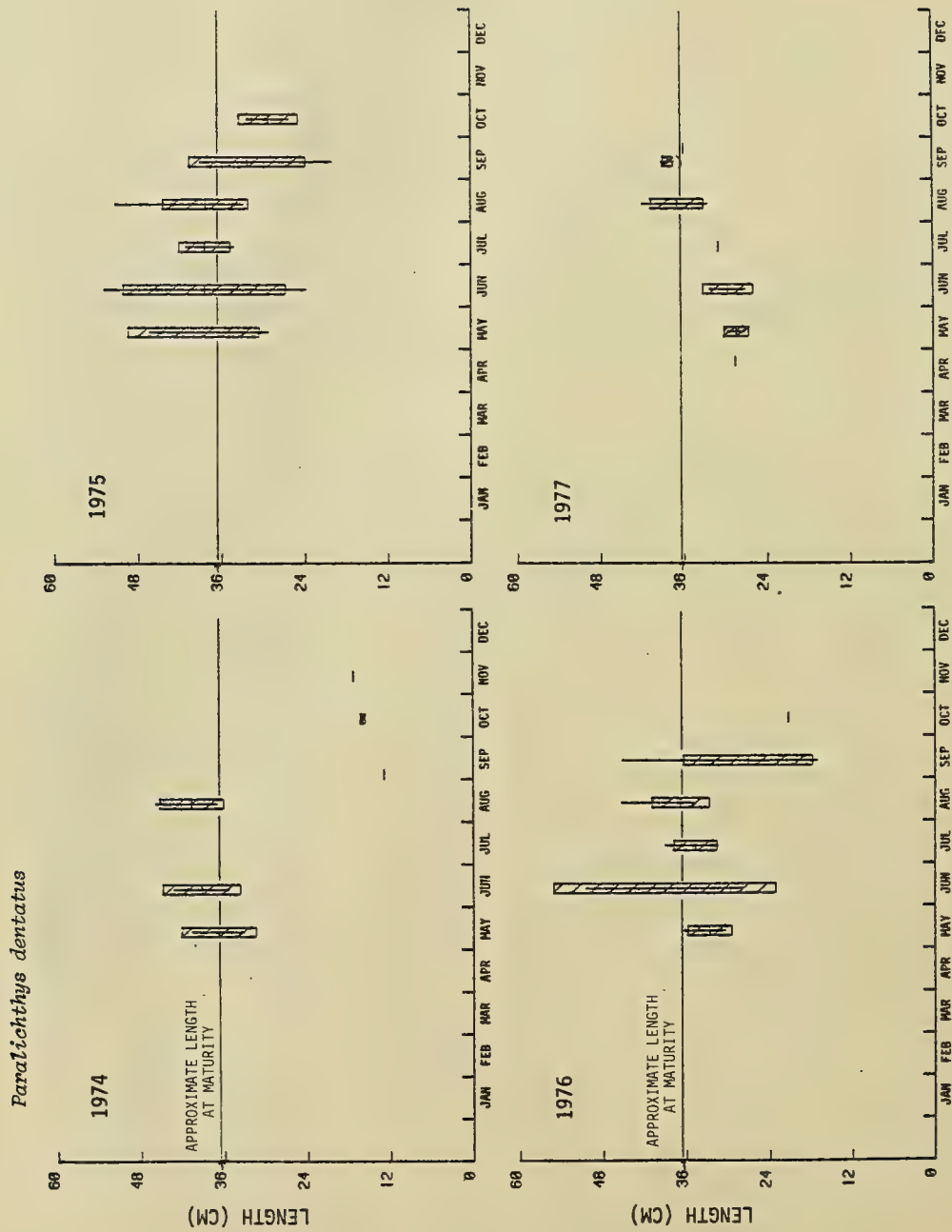


Figure 11-13. (Continued)

Richards (1963) found that herring sampled in New Haven Harbor fed on mysids (*Neomysis americana*) and various copepods, and stated that, if present in large schools, the herring might have considerable impact as a predator on these groups.

Herring are fish of the open ocean, usually traveling widely in schools of hundreds or thousands of individuals (Bigelow and Schroeder, 1953). Numbers recorded from New Haven Harbor collections were very small compared to commercial catches. Otter trawl catches of several hundred to a thousand fish occurred at Station 5, near Long Wharf. These large catches occurred in May and June from 1973 through 1975 (Figure 11-14) and consisted of young fish (3 to 8 cm long) about to enter their second year (Figure 11-15) (Bigelow and Schroeder, 1953).

Occasionally, single herring have been observed impinged on the traveling screens of New Haven Harbor Station. Data from other Long Island Sound facilities are comparable.

Judging from the ichthyoplankton data, spawning appears to occur locally in mid-winter. Peak larval densities have been recorded in March and April (0.003 to 0.03 individuals per m^3). The Port Jefferson facility has reported approximately 0.05 herring larva per m^3 during June and July, 1976. Large local differences in spawning season are typical of this species (Bigelow and Schroeder, 1953). The eggs are deposited over hard bottom to sink and adhere readily to any substrate; this demersal trait undoubtedly accounts for the absence of herring eggs in New Haven Harbor ichthyoplankton collections. The low observed density of larvae is similar to observations by Wheatland (1956) in Long Island Sound.

Menhaden (Brevoortia tyrannus)

More than any other herring-like fish, menhaden (particularly juveniles) are encountered in large schools close to shore where they

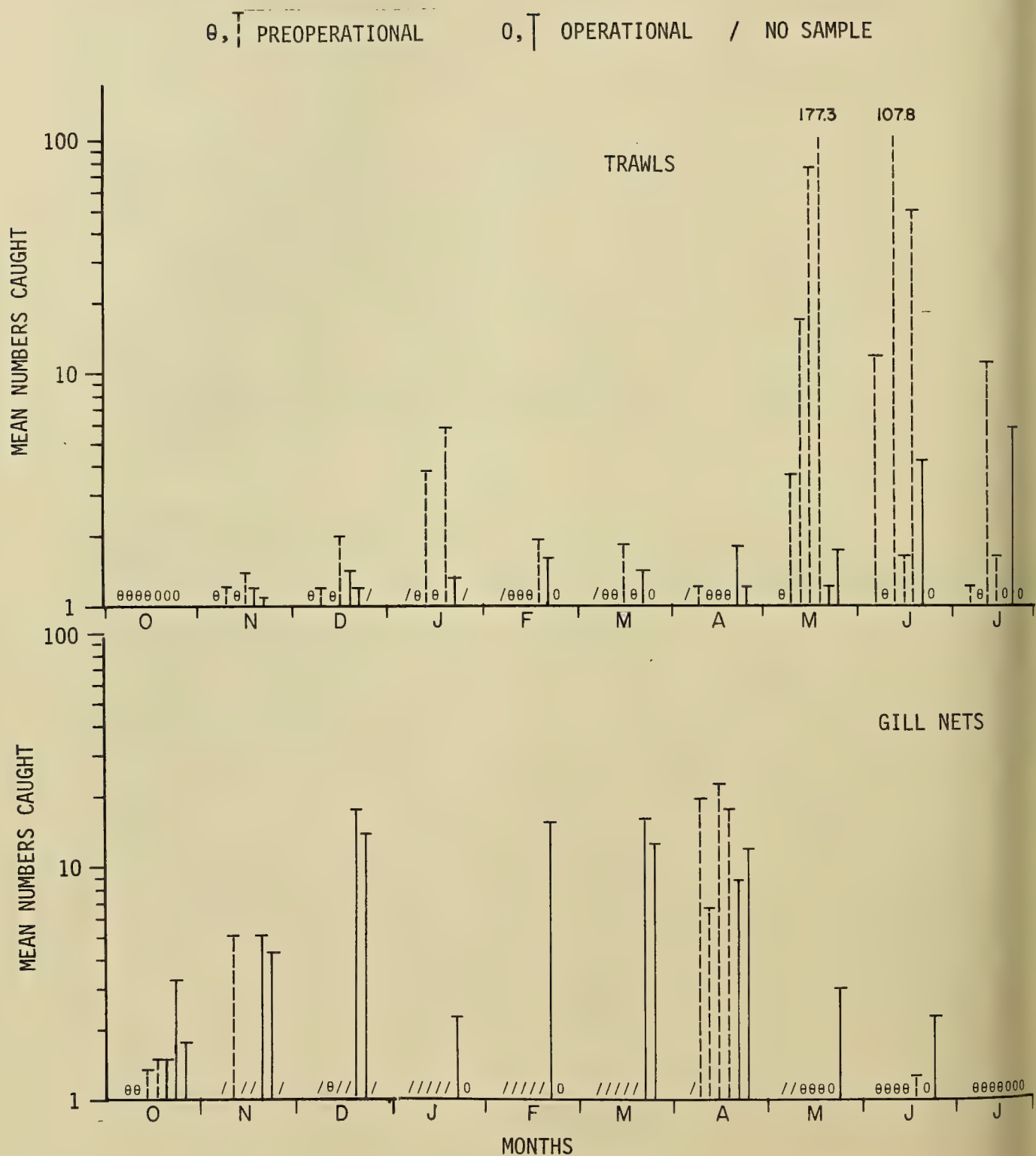


Figure 11-14. Monthly mean abundance of *Clupea harengus* collected by gill net and otter trawl from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

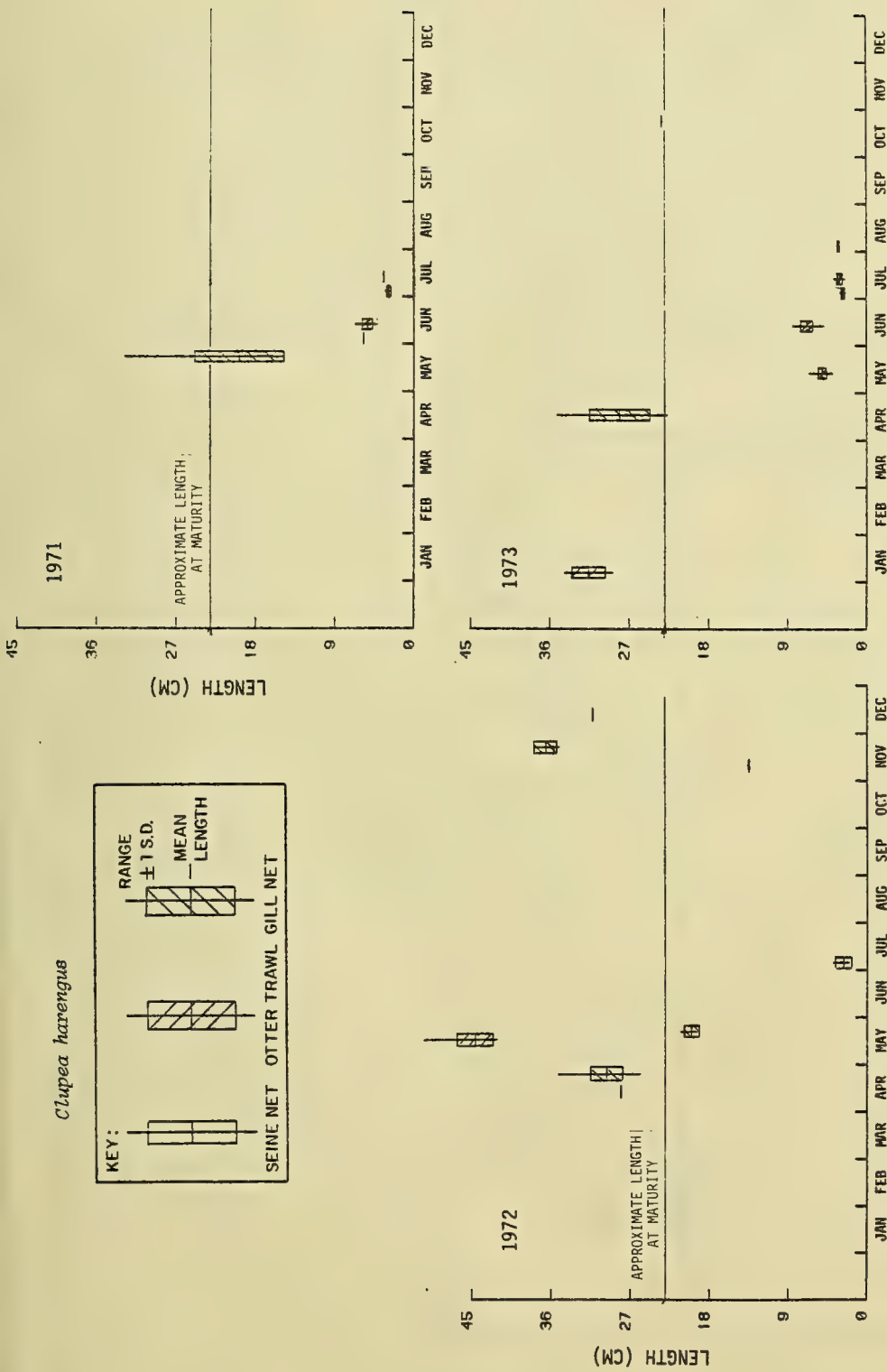


Figure 11-15. Total length (mean, range and std. dev.) of *Clupea harengus* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

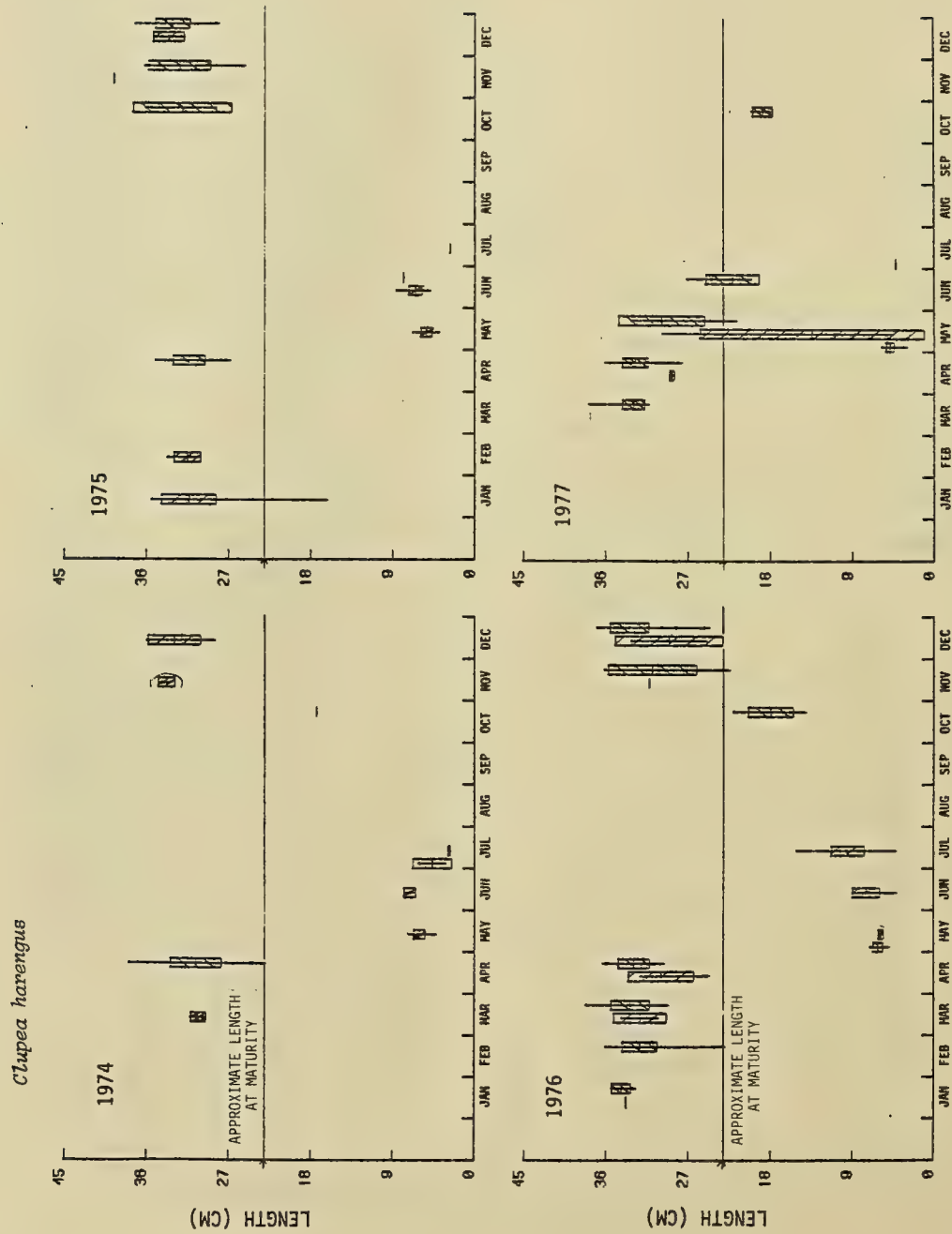


Figure 11-15. (Continued)

may be utilized by predators, particularly the bluefish (Bigelow and Schroeder, 1953). Menhaden are exploited extensively by commercial fleets for fish oil, meal and by-products (ASMFC, 1965).

Gill nets have accounted for most of the adult catch, which has fluctuated from year to year between a mean of 2.6 and 15.7 fish per net haul (Figure 11-16). Juveniles have been collected in more substantial numbers by beach seine and otter trawl (Figure 11-17), especially in 1971 and 1972 (up to 6800 fish per seine, and 390 fish per trawl). These large catches were taken in August, September, and October and consisted of young-of-the-year (Figures 11-16, 11-17). Along with the ichthyoplankton record, these data indicate a peak in utilization of New Haven Harbor as a menhaden nursery in 1972.

Menhaden are often the subject of massive "fish kills" (Westman and Nigrelli, 1955). Several recent kills of adults and juveniles have been observed to be associated with the thermal plumes produced by discharging heated water from power plants (Young, 1974), particularly when discharge is into a canal or other restricted area. Various explanations for the deaths have been suggested: one plausible underlying factor is suffocation brought about by the crowding; Oviatt, Gall and Nixon (1973) noted an approximate 12% reduction of dissolved oxygen concentration within menhaden schools; other possible causes include heat shock, cold shock, gas embolism, toxic effects of biocides and pollutants (Young, 1974). To maintain adequate oxygen supply to the gills (which also serve as the filtering apparatus for obtaining microplanktonic food) menhaden must constantly remain in rapid motion. Even 20 minutes of confinement in a 20-gal aquarium tank is lethal for juvenile fish (3 to 7 cm long). On the other hand, other juveniles can be kept alive for several days in a flume (author's observation).

Available records indicate that New Haven Harbor has been a site of large fish kills involving menhaden, both before and after New Haven Harbor Station began operation. Records maintained by the Conn-

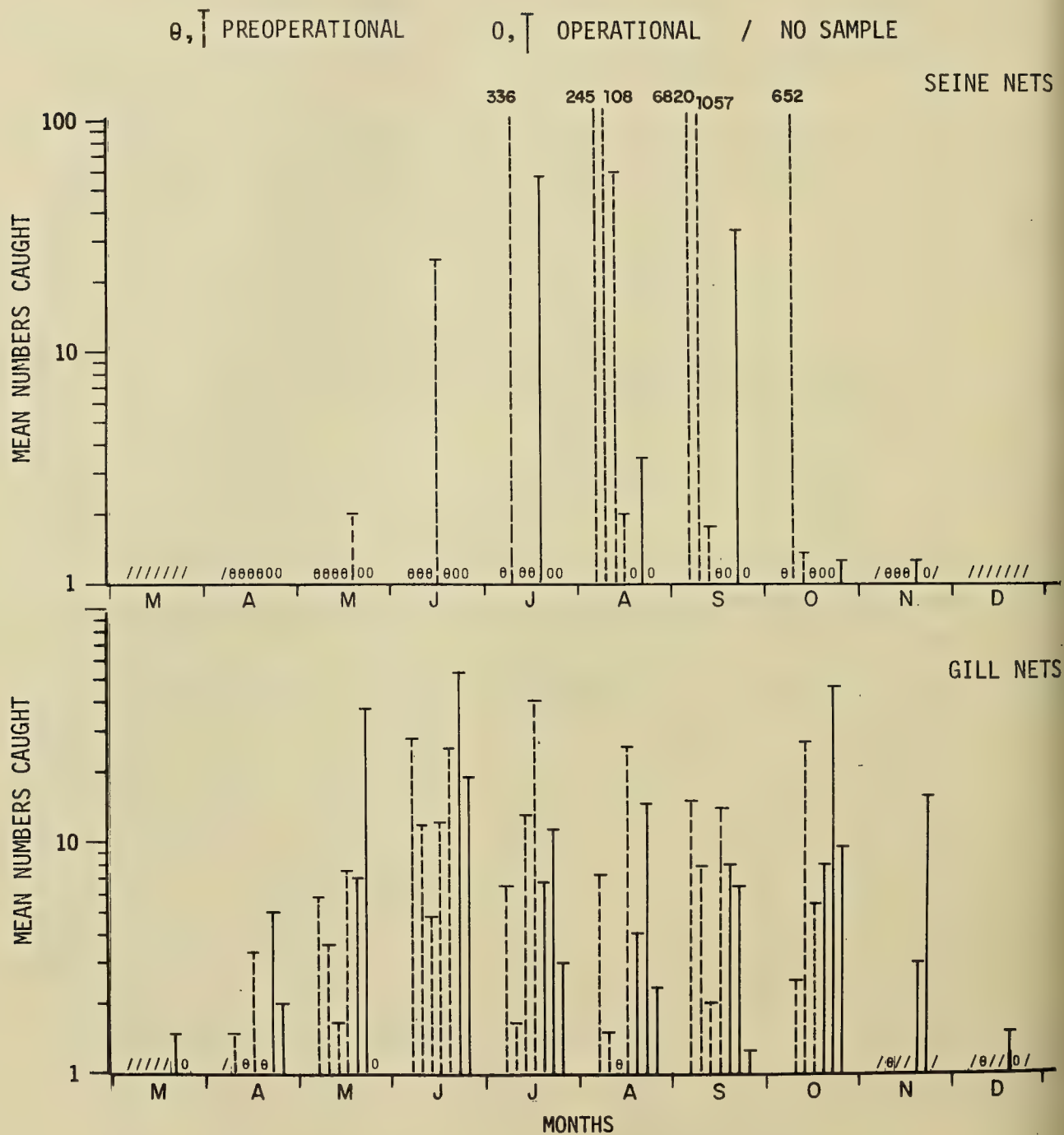


Figure 11-16. Monthly mean abundance of *Brevoortia tyrannus* collected by seine and gill net from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

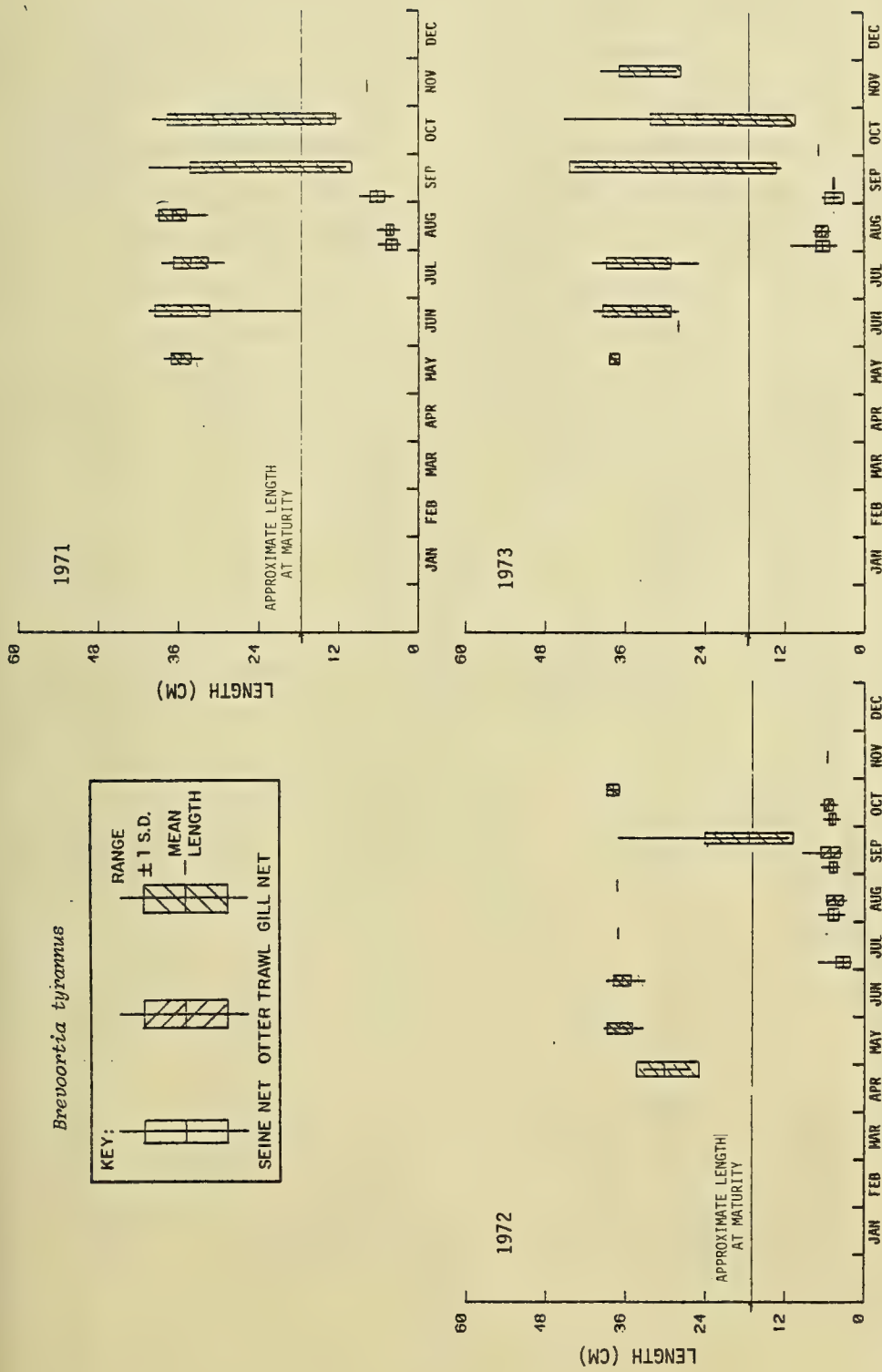
Brevoortia tyrannus

Figure 11-17. Total length (mean, range and std. dev.) of *Brevoortia tyrannus* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1979. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

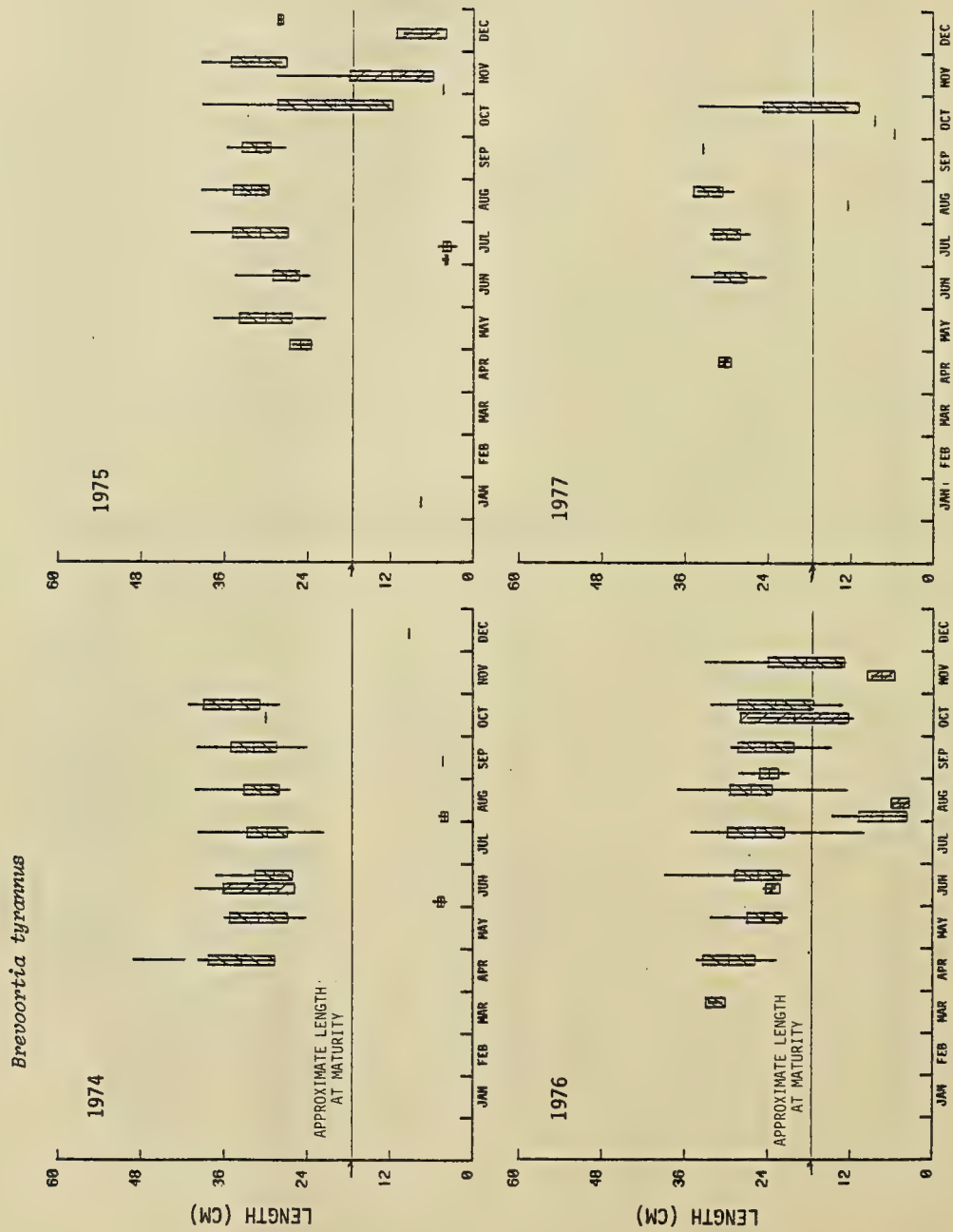


Figure 11-17. (Continued)

ecticut DEP show that several kills, involving tens of thousands of menhaden, occurred in New Haven Harbor during the summer of 1974. Similar, but poorly documented events have occurred nearly every year in the present decade. Connecticut occurrences have been attributed by Connecticut DEP staff to pollution by industrial and municipal wastes and/or low ambient dissolved oxygen concentrations. These mass mortalities are not confined to New Haven Harbor, but occur in estuaries all along the Atlantic coast with varying severity and frequency and are prevalent in pristine waters as well as polluted.

Substantial impingement of menhaden on traveling screens of New Haven Harbor Station was first detected in June 1976 and continued through December of that year (Figure 11-18). Before and after this period, however, impingement of menhaden was negligible. At its peak, during the third and fourth week in July 1976, the New Haven Harbor Station impingement rate averaged more than 600 juvenile menhaden per day. This was approximately four times the highest impingement rate for this species at Devon, a smaller generating station on the Housatonic River which utilizes about 50% as much cooling water as New Haven Harbor Station. The problem is of lower magnitude at most other power plants in the Long Island Sound area. Menhaden impingement has been much greater at Salem and Brayton Point, MA; Astoria, NY; Surry, VA and Brunswick, NC (Stupka and Sharma, 1977). Also, to put impingement losses in their proper perspective, it should be recalled that menhaden typically die by the tens and hundreds of thousands during "fish kills." Resulting dead fish may be drawn onto the traveling screens by the intake currents, where they are counted as impinged fish.

Menhaden become sexually mature around age III when they are over 18 cm long (Westman and Nigrelli, 1955). In Long Island Sound, spawning occurs from May through October, with peaks of larval abundance in June, July or September (Wheatland, 1956; Richards, 1959). Recent evidence from Port Jefferson, Glenwood (LILCO, 1978), and New Haven Harbor ichthyoplankton collections support these observations. New

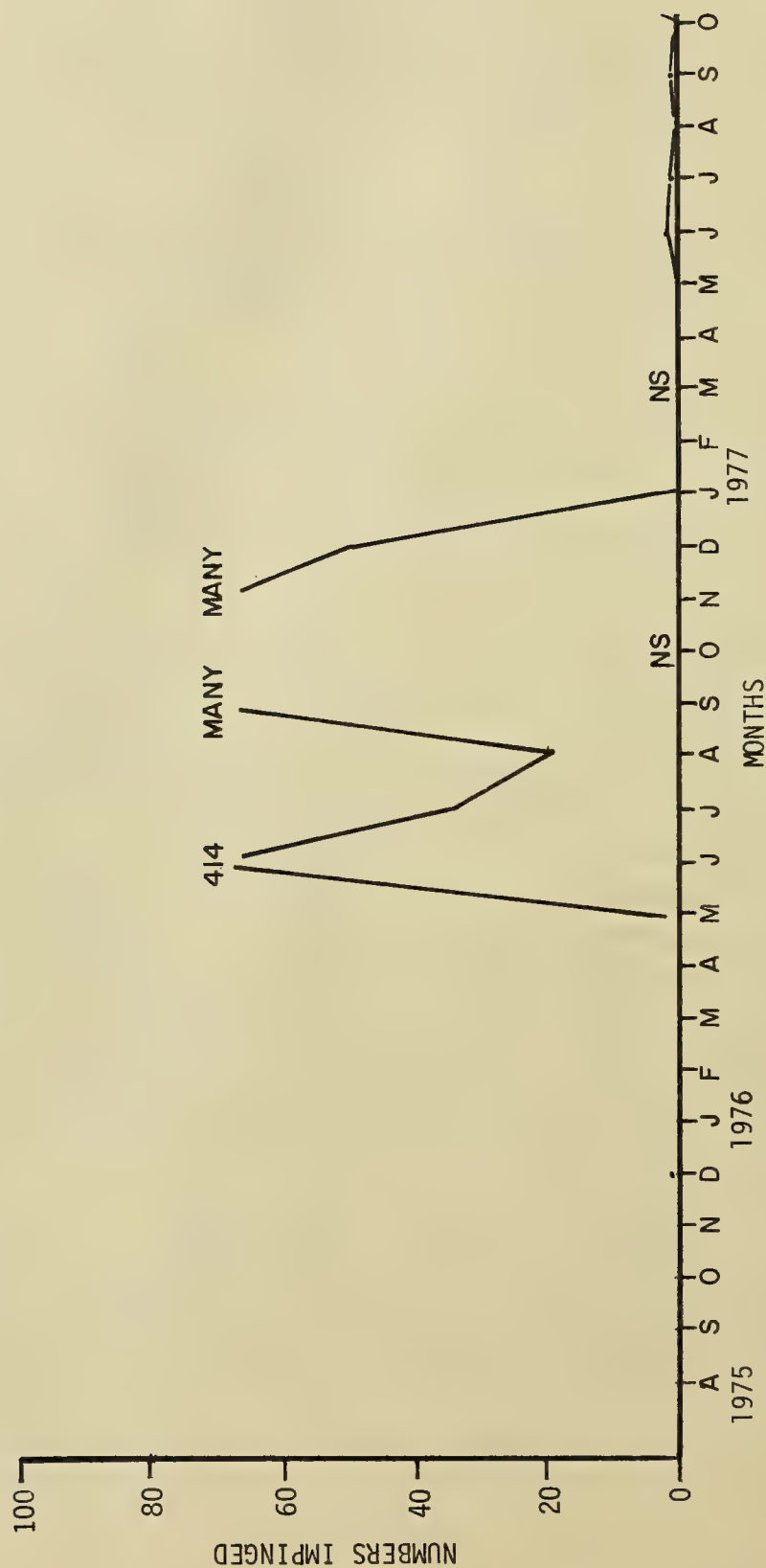


Figure 11-18. Mean daily impingement of menhaden (*Brevortia tyrannus*) by month at the New Haven Harbor Station; August 1975 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Haven (1971 and 1972) and 1976 Northport (LILCO, 1978) data indicate July to be the peak month for catches of menhaden larvae.

Densities of menhaden larvae collected in New Haven Harbor in July of 1971 and 1972 (2.26 and 0.57 per m^3 , respectively) were higher than larval densities more recently reported for New Haven Harbor and other Long Island Sound power plant studies. The highest menhaden egg densities in New Haven Harbor (0.05 per m^3) were reported in June 1977, relatively low compared to peak densities reported for Glenwood (5.41 per m^3), Millstone (18.84 per m^3 , NUSCO, 1977) and Northport (1.1 per m^3 ; LILCO, 1974). It would appear that principal spawning grounds are remote for New Haven Harbor but that in some years, (e.g., 1971 and 1972), currents may carry the larvae into the harbor in considerable numbers. Menhaden are believed to spawn offshore rather than in estuaries. Nelson, Ingham and Schaaf (1977) showed that larvae are probably transported shoreward and into estuaries by physical processes.

Alewife (Alosa pseudoharengus)

The alewife is a schooling fish related to the herring but differing markedly in that it is anadromous. Almost any freshwater body above the influence of the tide is suitable for spawning so long as it is accessible from the sea and has some stretches of slow-moving water. Spawning runs that may occur locally take place in late winter or early spring (March, 1976). Adult alewives typically return to the ocean soon after spawning, while the juveniles remain in freshwater their first summer, migrating downstream from late summer through fall (Bigelow and Schroeder, 1953). Alewives feed primarily on large copepods and mysids (Richards, 1963).

Small numbers of juvenile and adult alewives (averaging from 5 to 30 cm long) have been captured in New Haven Harbor by beach seine, otter trawl and gill net in this study (Figure 11-19). The largest seine catches (approximately 40 to 100 fish) have occurred in July, in

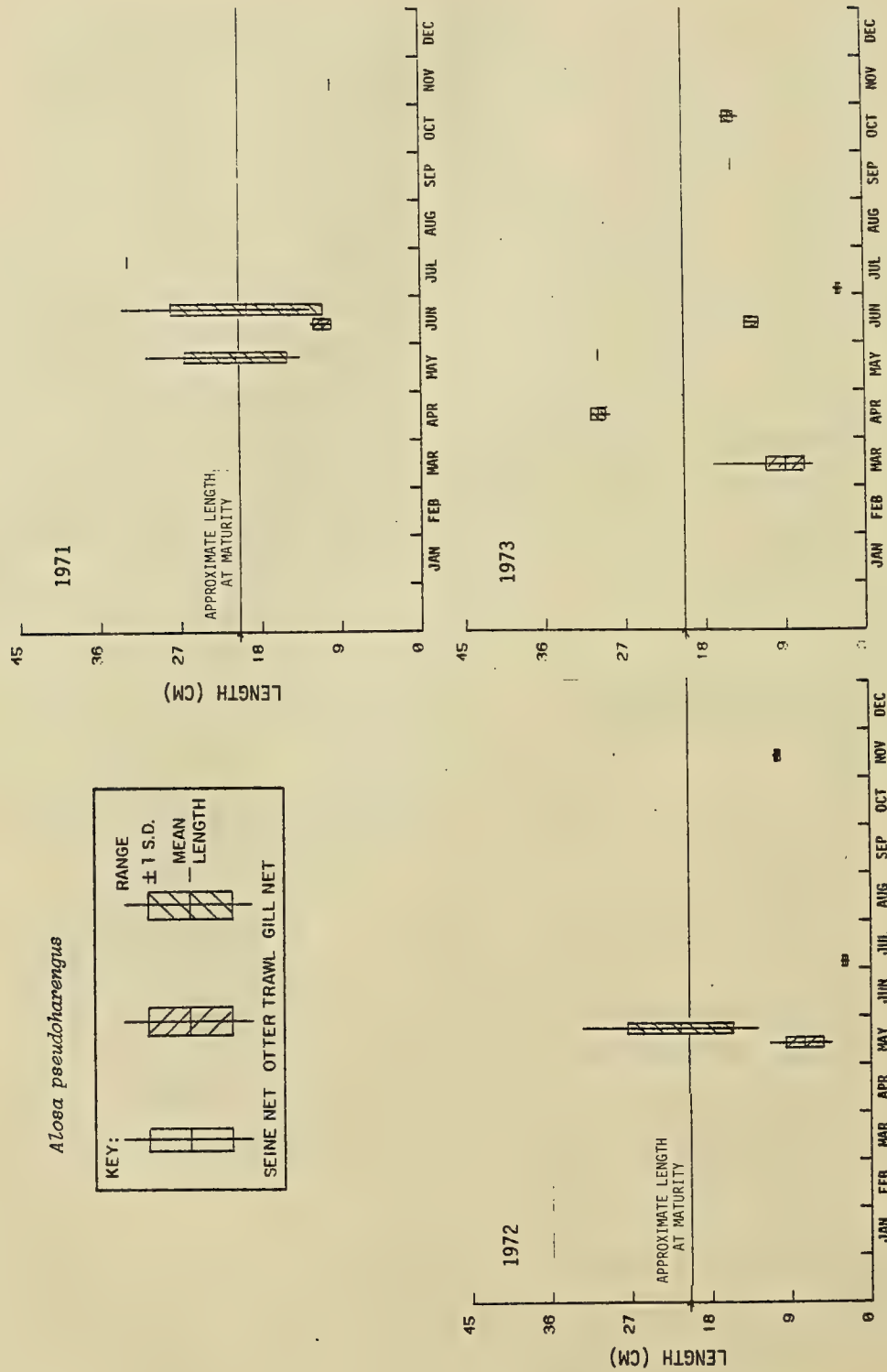


Figure 11-19. Total length (mean, range and std. dev.) of *Alosa pseudoharengus* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

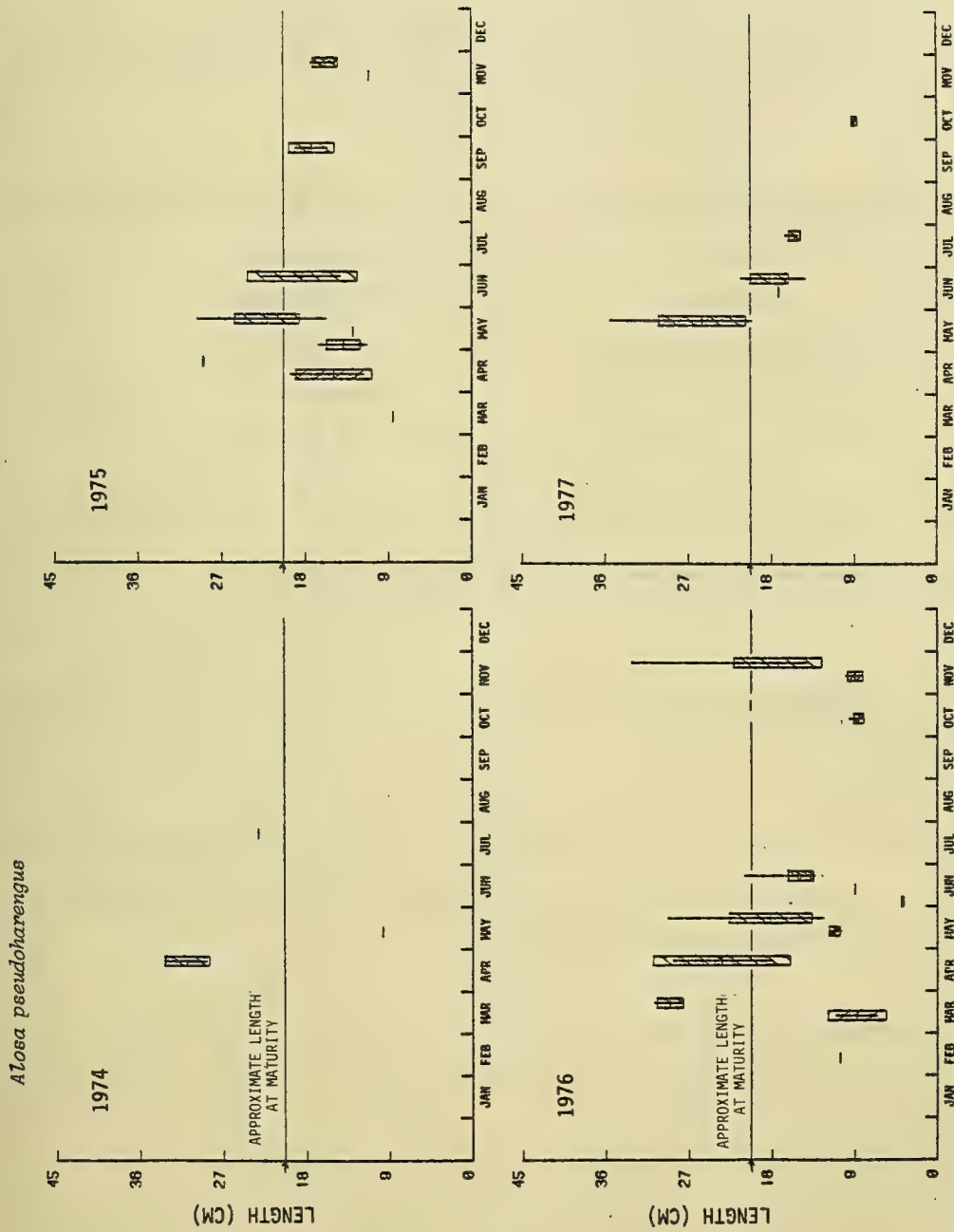


Figure 11-19. (Continued)

both 1972 and 1973 (Figure 11-20). Comparable otter trawl catches (30 to 200 fish) have been recorded for March 1973 and May 1972. Various gill-net stations have yielded catches of 20 to 40 fish in May or June for the years 1975, 1976, and 1977. The sporadic occurrence of these catches, with no recognizable spatial pattern, suggests that the fishes caught were in transit to spawning grounds (March, 1973) or returning from spawning (May-July). Overall, it is apparent that visits of substantial numbers of these fish are restricted to spring and early summer.

Only one impinged alewife has been reported (on 28 July 1977) since the inception of the weekly traveling screen census at New Haven Harbor Station. Compared to the frequency of impingement reported at other Long Island Sound power plants, this is an extremely low rate. Alewife larvae have never been reported in ichthyoplankton collections because larvae mature into juveniles and remain in freshwater until fall; therefore, it is difficult to assess the magnitude of the local reproductive effort. The eggs adhere to freshwater stream substrates so it is unlikely they would be abundant in Harbor collections.

Blueback Herring (Alosa aestivalis)

The blueback herring is so similar in appearance and habit to the alewife that even experienced fishermen frequently mistake one species for the other. The range of the blueback, however, extends further southward than that of the alewife.

Blueback herring have proven to be at least as infrequent in New Haven Harbor collections as the alewife. Juveniles (4 to 5 cm long) were particularly abundant in otter trawl collections of August 1971 (up to 1560 fish) and in the beach seine hauls of July 1972 and 1973 (up to 1700 fish) (Figure 11-21). Since that time, however, neither collection method has yielded more than ten fish of any size in any one sample (Figure 11-22).

(Text continued on page 11-63)

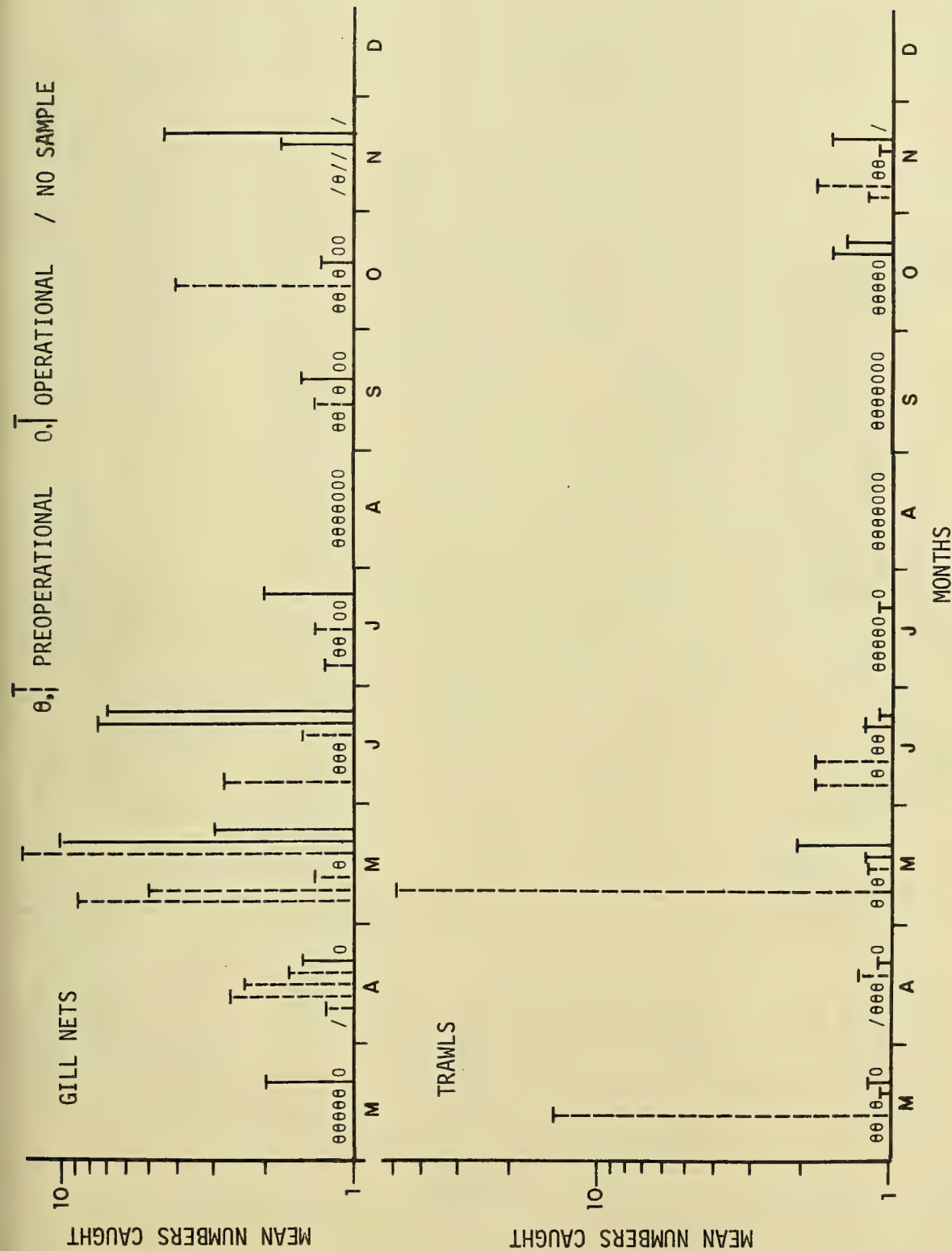


Figure 11-20. Monthly mean abundance of *Alosa pseudoharengus* collected by gill nets and other trawls from 1971 through 1977. New Haven Harbor Station Ecological Studies Summary Report, 1979.

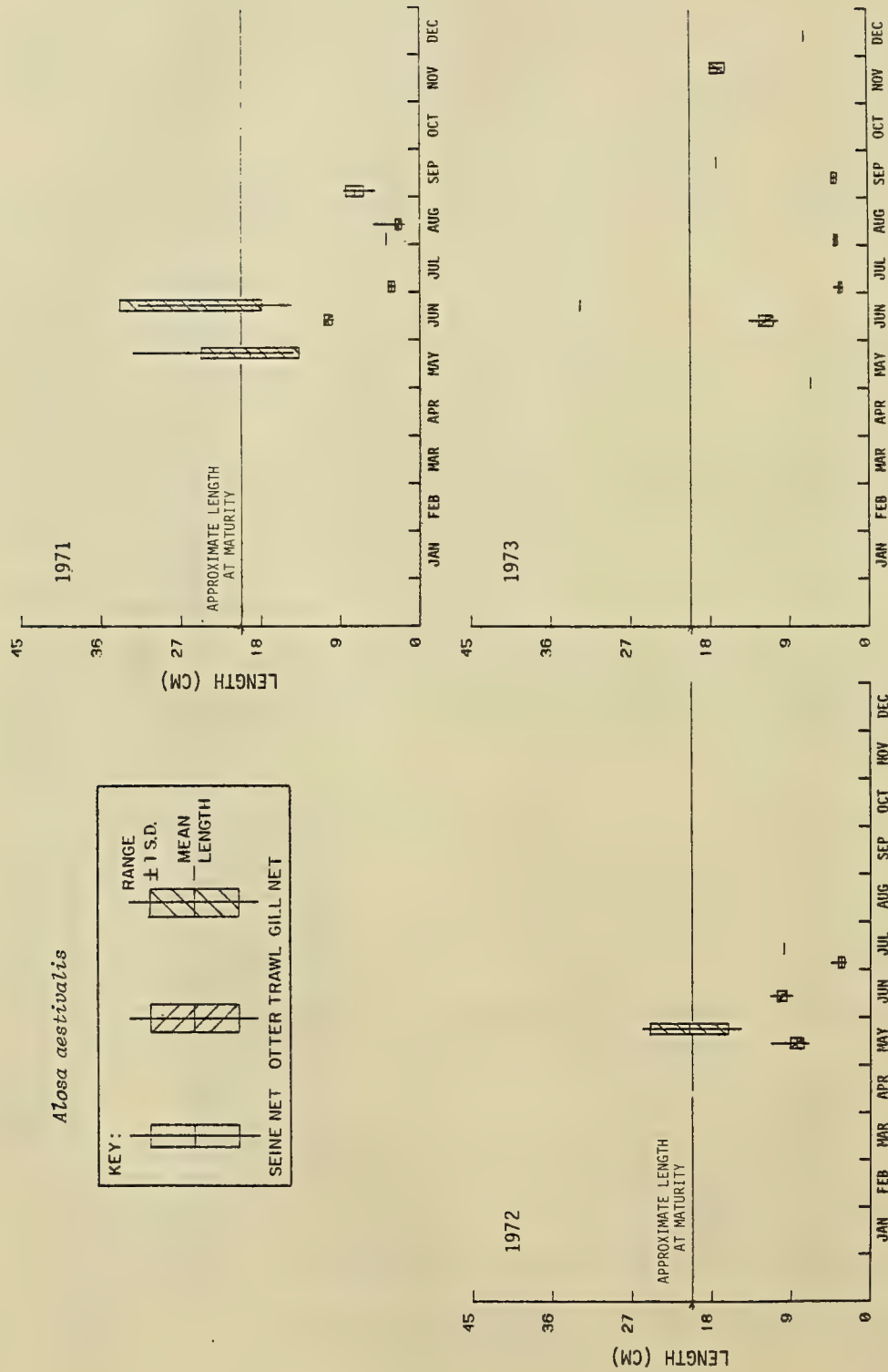


Figure 11-21. Total length (mean, range and std. dev.) of *Alosa aestivialis* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1979. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

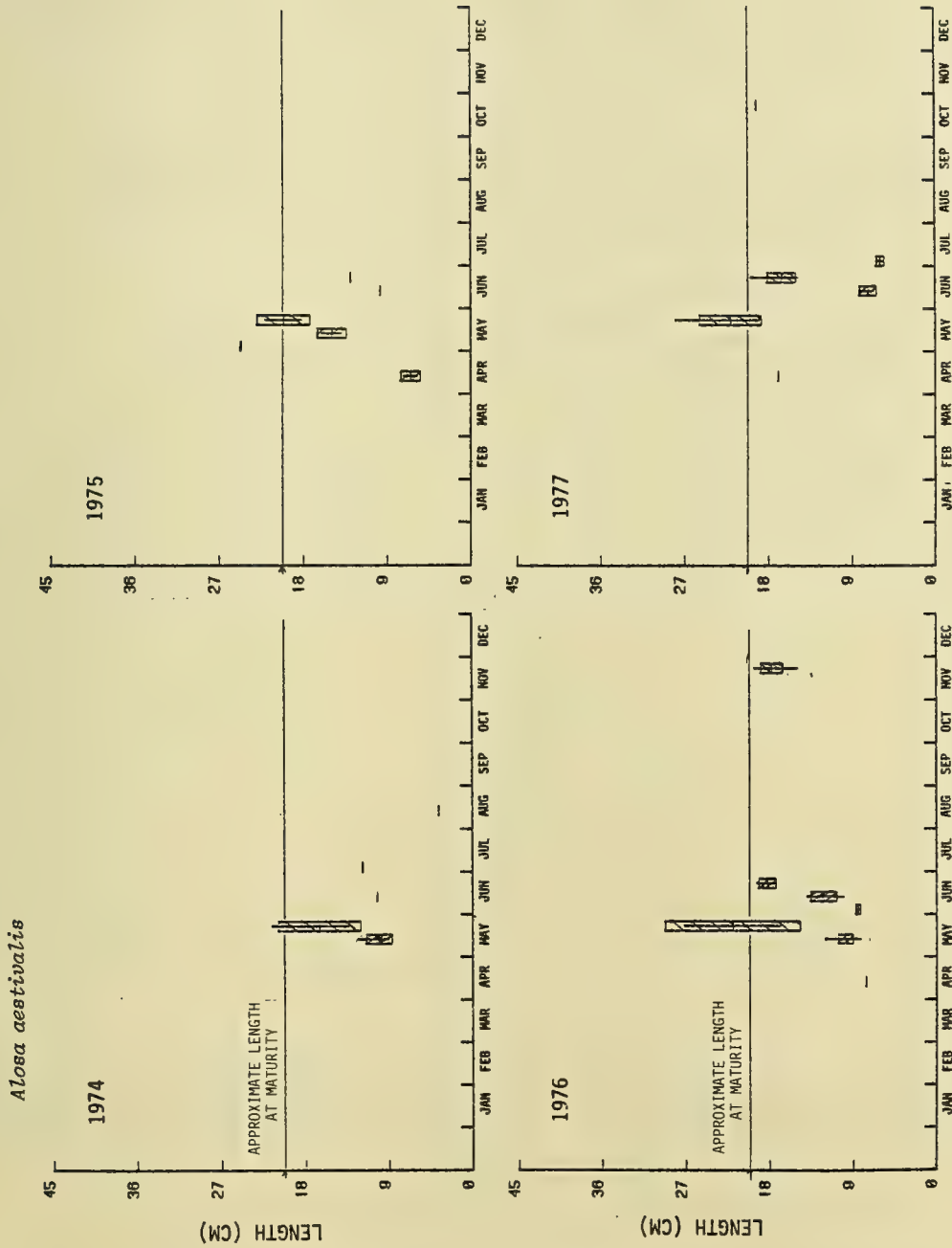


Figure 11-21. (Continued)

Figure 11-22. Monthly mean abundance of *Alosa aestivalis* collected by gill nets and otter trawls from 1971 through 1977. New Haven Harbor Station Ecological Studies Summary Report, 1979.

Marcy (1976a) states that this species spawns later in the year than the alewife (when the water over the spawning ground is approximately 21-25°C), and does not run up as far above tidewater to spawn. Bluebacks may have utilized freshwater spawning areas in the vicinity of New Haven Harbor in recent years. In 1971 and 1972, blueback larvae were reported in July and June, respectively; however, we believe that these data were incorrect identifications of anchovy larvae. Since then, no larvae of this species have been reported. Together with the seine and trawl catch record, these findings would suggest that local spawning of blueback herring may have been prevalent in the early 1970's but has since declined below detectable levels.

New Haven Harbor traveling-screen data indicate relatively high impingement rates (30 to 60 fish per day) for only two dates: one in early June 1976, the other in early December 1977. Average impingement rates are much lower than this. For the June-July 1976 sample period, there had been less impingement of this species than at other generating stations reviewed.

Rainbow Smelt (Osmerus mordax)

The smelt is an anadromous species, popular as a sport and food fish (Bigelow and Schroeder, 1953). This species also constitutes a major prey item for salmonids and other large gamefish. As with other anadromous species, disruption of spawning habitat has greatly reduced the utilization of heavily-populated coastal areas by this species.

In marine waters, smelt rarely stray more than a mile or two from shore (Bigelow and Schroeder, 1953). They also prefer cool water (8-9°C); thus, during summer, most leave harbors and shallow embayments for the cold bottom waters along the open coast. With the return of colder temperatures in the fall, the smelt return to the harbors and embayments in preparation for the spring spawning run to gravel-bottomed freshwater streams.

Of the three methods used to sample juvenile and adult finfish, the otter trawl has been by far the most effective for capturing smelt. Juveniles (3 to 14 cm) have been captured in New Haven Harbor during every month except October (Figure 11-23). Smelt were caught in record numbers (up to 1140 fish per tow) during the first three months of 1973 (Figure 11-24). The years before and after 1973 have produced comparatively meager catches of no more than 26 to 70 juveniles per tow. Extremely wide fluctuations in catch, due to irregular utilization of specific nursery grounds, are not unusual for this species. Smelt were not abundant in New Haven Harbor nor were they at Shoreham (NYOSL, 1974), in Long Island Sound (Richards, 1963) or the Mystic River Estuary (Pearcy and Richards, 1962). Eggs (adhesive) and larvae were observed in New Haven Harbor only during 1977. The peak densities in April (0.02 eggs per m³) represent nominal contribution from freshwater areas.

American Shad (Alosa sapidissima)

The geographic distribution of shad is principally associated with sizeable streams, such as the Connecticut River, where great numbers of these fish undertake long journeys to spawn (Leggett, 1976). By restricting passage to the upstream spawning areas, the construction of dams has done more to severely limit shad populations than any other act of mankind. Commercial fisheries exist for this species, and there are now federal and state programs to restore shad migrations to some of New England's larger rivers. Shad are planktivorous, feeding largely on copepods (Bigelow and Schroeder, 1953).

Juvenile and adult shad (3 to 54 cm) were captured in New Haven Harbor otter trawls, gill nets and seines from April through July and October through December (Figure 11-25). Rarely, however, have more than a dozen individuals been taken from the same sampling station on the same collection date. The exceptions have been 1) November 1975, when 56 juvenile shad (10 to 15 cm) were taken by otter trawl at Station 5; and, 2) May and June 1976, when, respectively, 38 (Station 8A) and 62

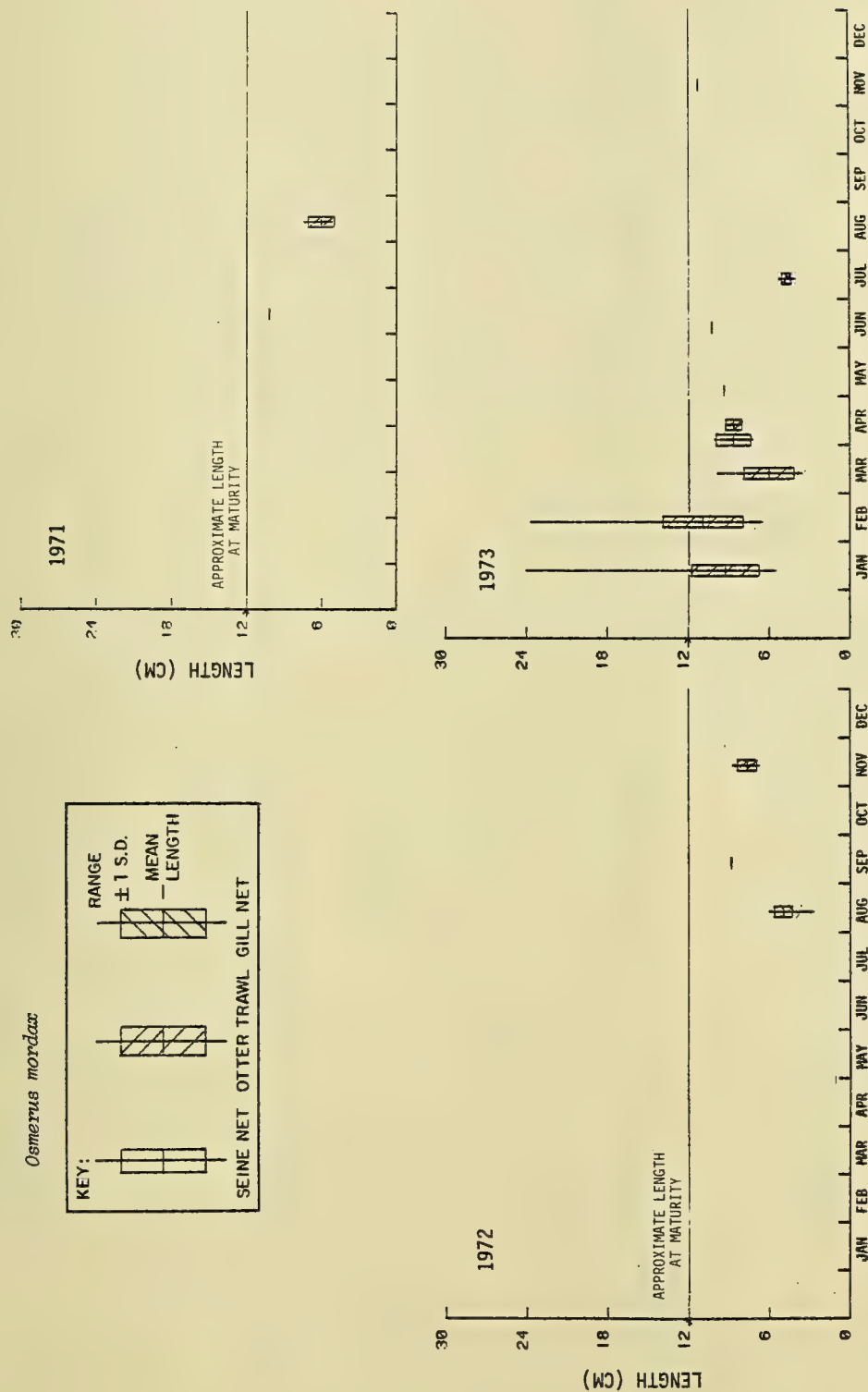


Figure 11-23. Total length (mean, range and std. dev.) of *Osmerus mordax* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

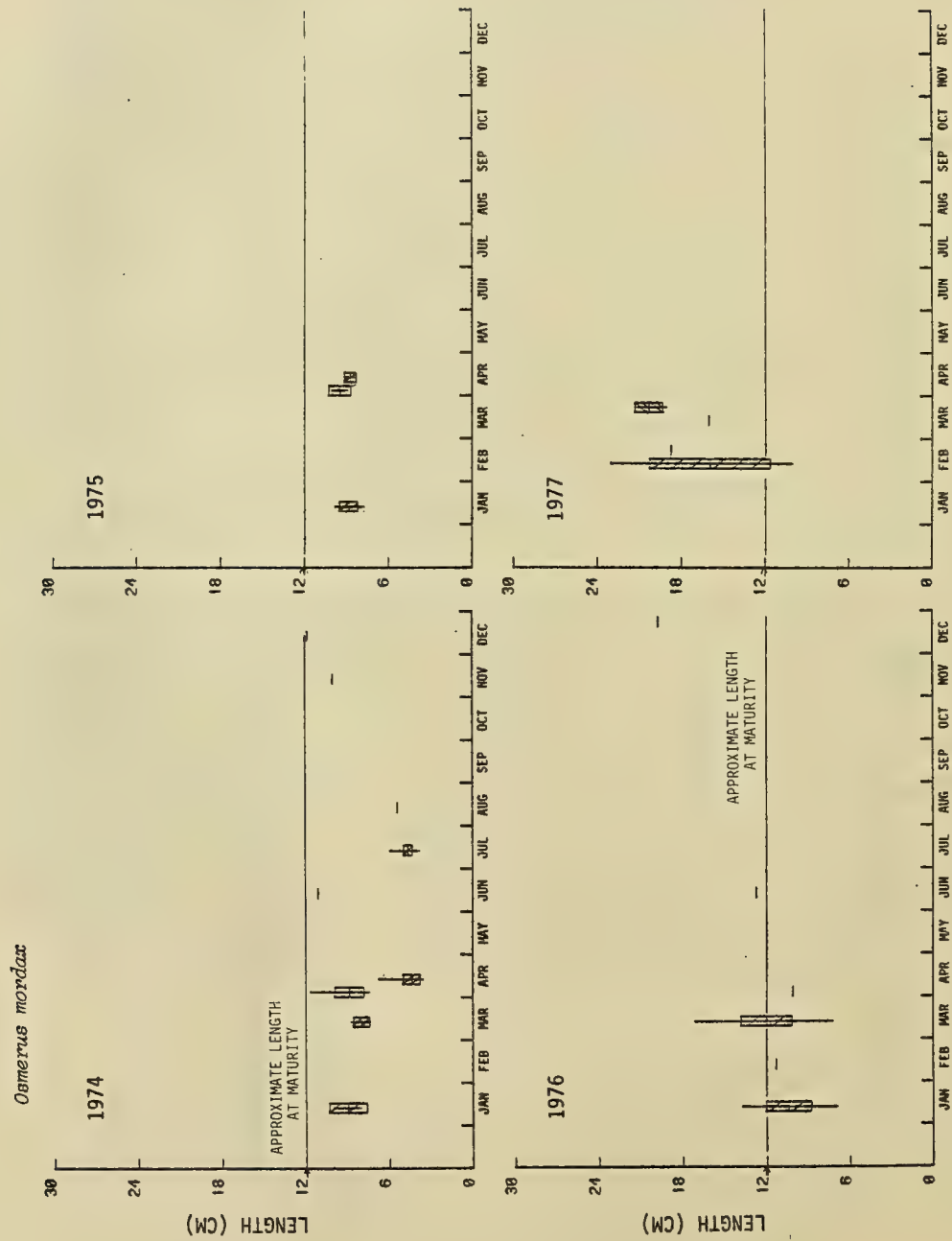


Figure 11-23. (Continued)

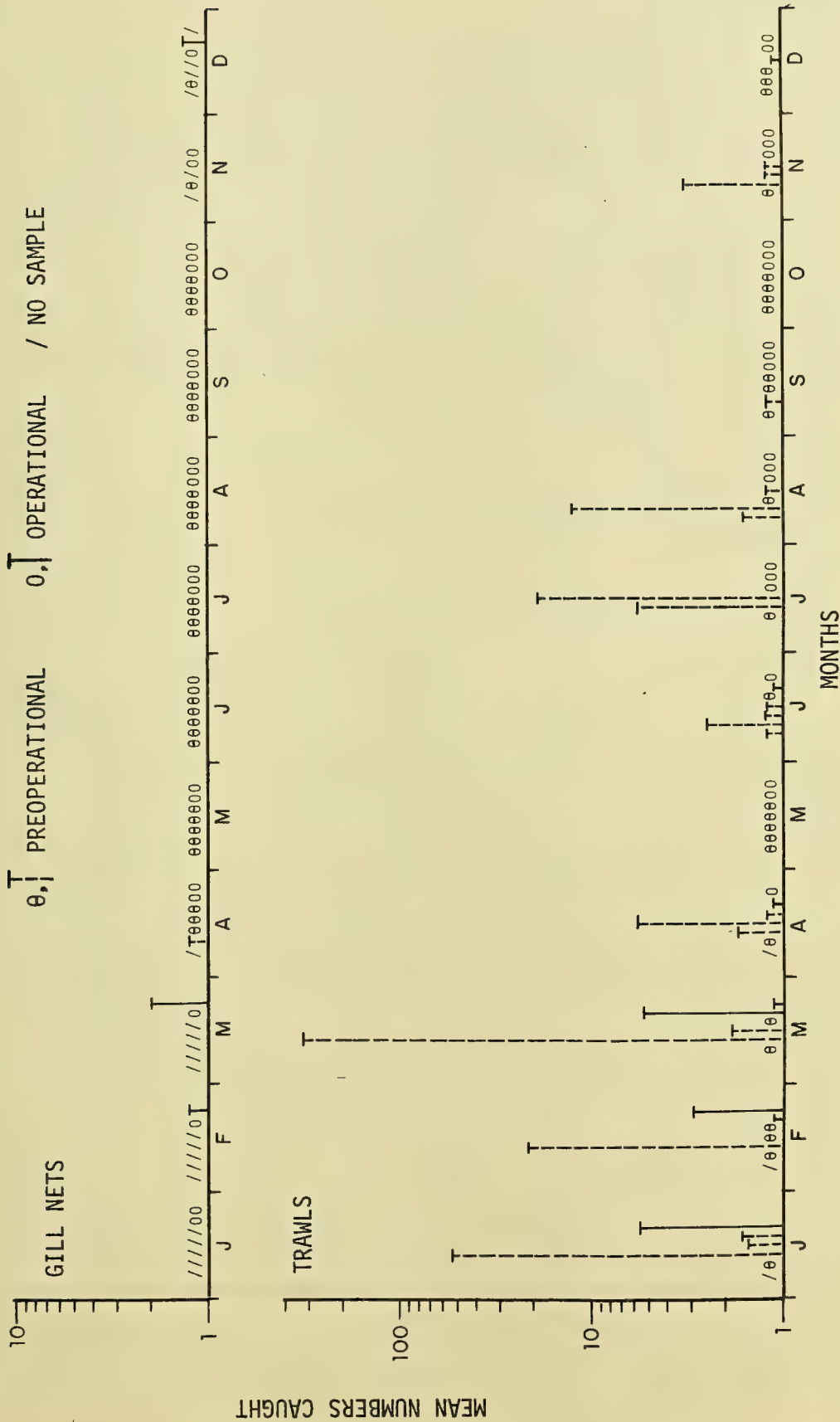


Figure 11-24. Monthly mean abundance of *Osmerys mordax* collected by gill nets and other trawls from 1971 through 1977. New Haven Harbor Station Ecological Studies Summary Report, 1979.

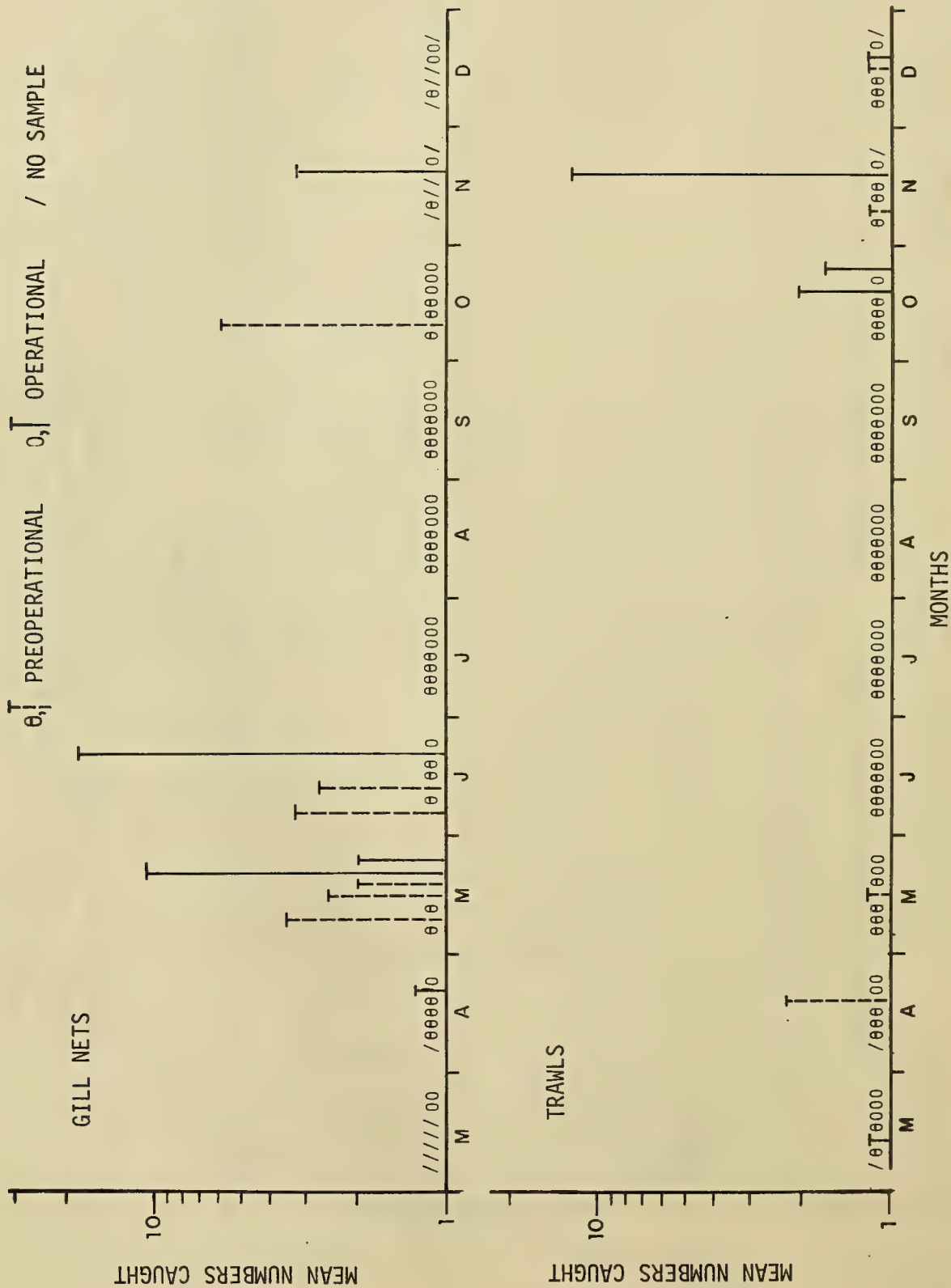


Figure 11-25. Monthly mean abundance of *Alosa sapidissima* collected by gill nets and other trawls from 1971 through 1977. New Haven Harbor Station Ecological Studies Summary Report, 1979.

(Station 13) yearling shad (15 to 23 cm long) were recovered from gill nets. Similar quantities of shad were caught at Millstone Point in 1976 (NUSCO, 1977). Richards (1963), Percy and Richards (1962) found no shad in their Long Island Sound and Mystic River Estuary samples. There is no record of any shad being impinged on New Haven Harbor Station traveling screens.

In Long Island Sound tributaries (primarily the Connecticut River), spawning activity peaks in late April or early May; the timing of spawning is regulated primarily by water temperature (approximately 13-18°C; Leggett, 1976). No shad eggs or larvae were collected in New Haven Harbor, nor would they be expected because the larvae and juveniles typically remain in freshwater throughout their first summer, migrating downriver to the ocean in the fall as river temperatures are 23-18°C (Marcy, 1976b).

Bay Anchovy (Anchoa mitchilli)

Anchovies are small warm-water fish seldom exceeding 8 cm in length (Hildebrand, 1943). Anchovies occur from the Gulf of Mexico to the southeastern Massachusetts coast, and are abundant along the open coastline out to approximately the 20 meter depth, and in estuaries and embayments as well. Because of their small size, anchovies were not quantitatively sampled by the otter trawl. Not all sizes were equally susceptible to capture, and data are subject to substantial sampling error. This problem was also encountered by Richards (1963) in Long Island Sound, who described "enormous quantities" of *Anchoa* in one fall catch.

Adults and juveniles (2 to 8 cm long) (Figure 11-26, 11-27) have been captured in otter trawls and beach seines with increasing frequency in recent years. In 1971, otter trawl captures were limited to the month of August. By 1976, however, anchovies were occurring in the trawl catches from April through November. Record catches of 15

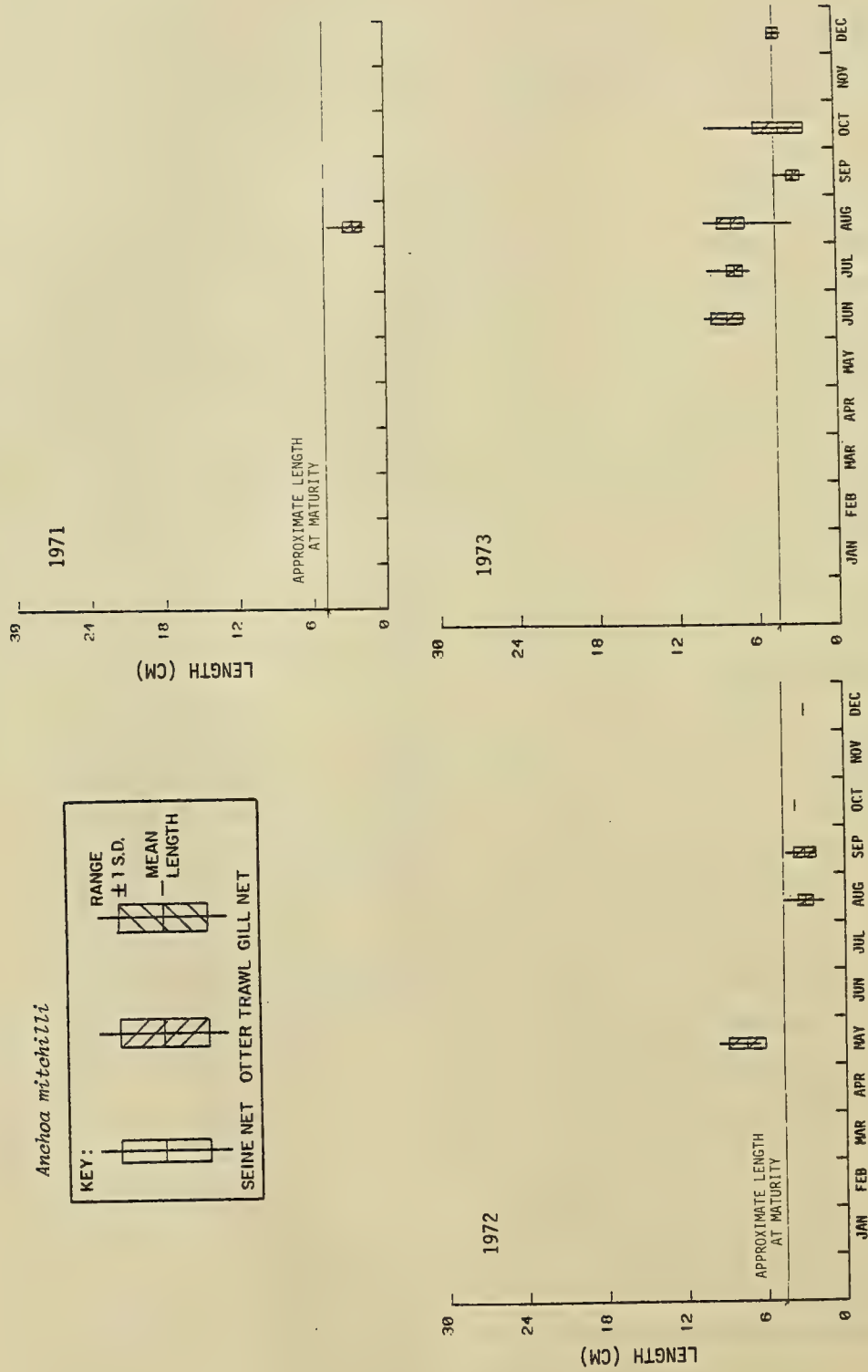


Figure 11-26. Total length (mean, range and std. dev.) of *Anchoa mitchilli* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

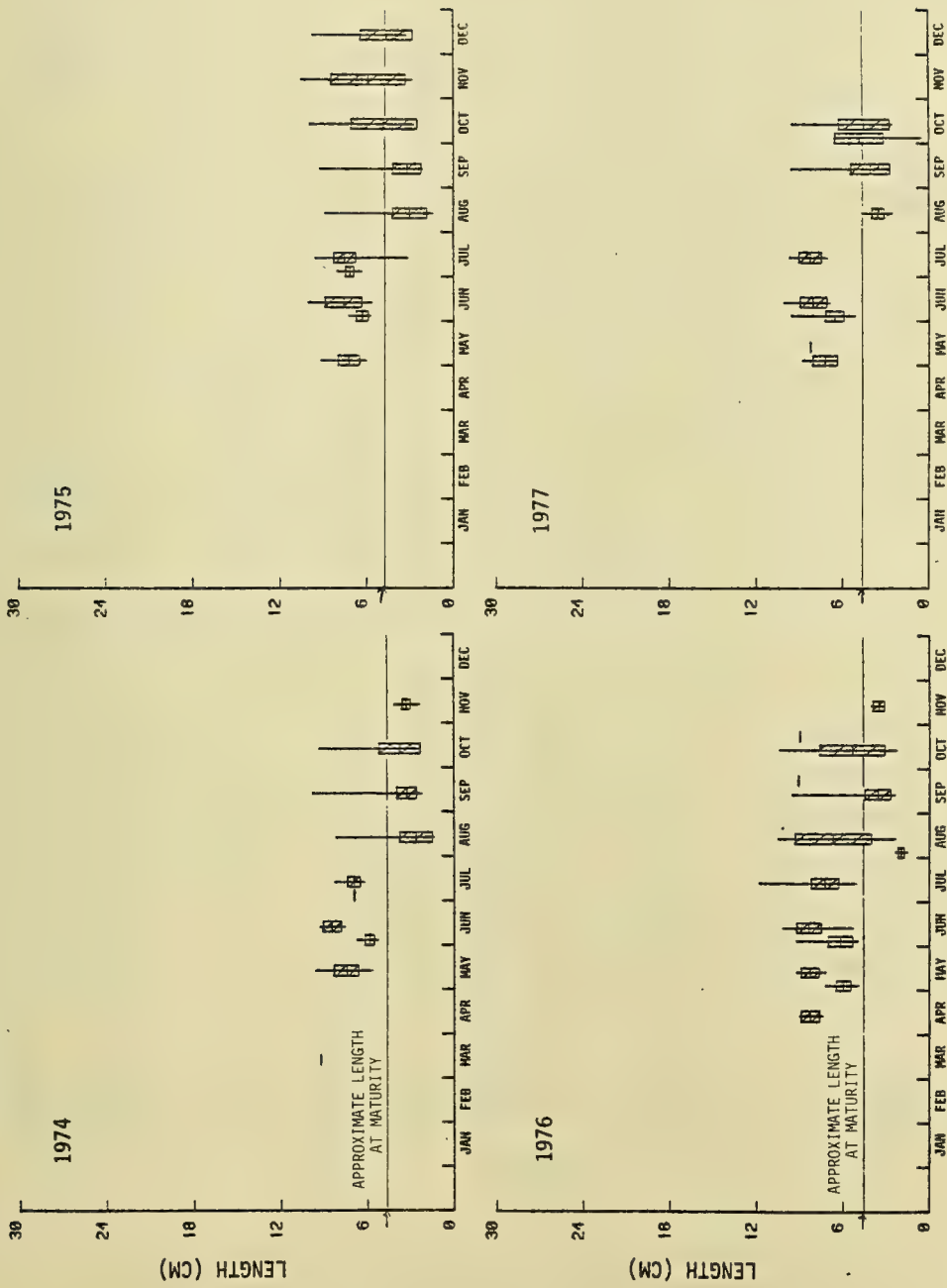
Anchoa mitchilli

Figure 11-26. (Continued)

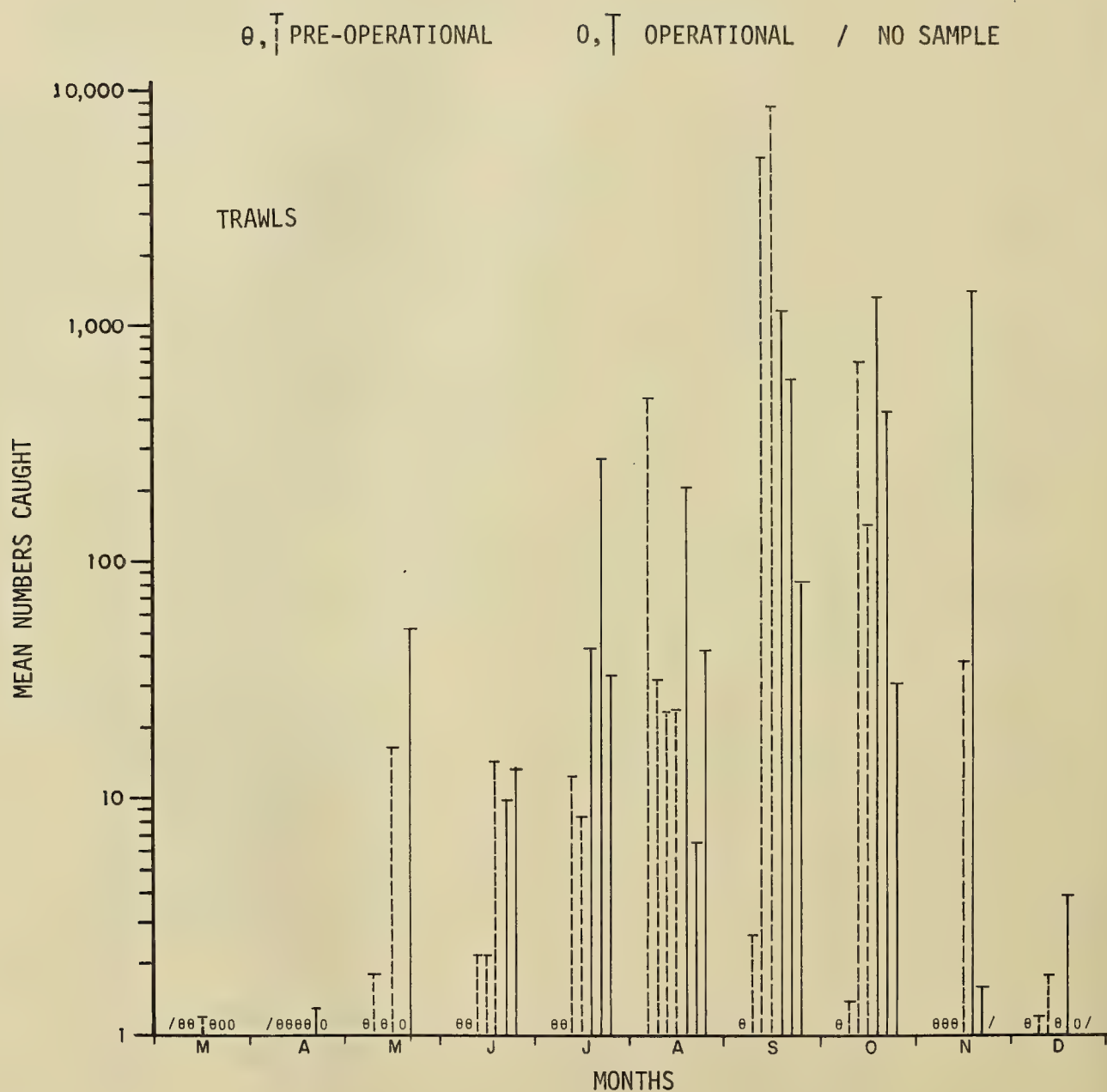


Figure 11-27. Monthly mean abundance of *Anchoa mitchilli* collected by trawls from 1971 through 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

thousand to 20 thousand fish per tow occurred in September in 1973 and 1974. From 1973 through 1975 the highest yields were from Station 5 and Station 19. These two stations have little in common except that they are both on the western side of the harbor remote from the site of New Haven Harbor Station. From 1975 to 1977 otter trawl catches have declined somewhat, although anchovies still occurred more frequently in 1977 catches than in 1971 and 1972 catches.

Beach seine catches exhibited a slightly different temporal pattern (Figure 11-26). Anchovies were not taken by seine until 1974, when the catch (totalling 57 fish) was restricted to the months of June and July. Both catch frequency and abundance increased in 1975 and 1976, with anchovies taken at 3 of the 4 sampling locations. In 1977, the average catch per effort during the peak month of June was approximately 150 fish. No anchovies were taken at the Long Wharf station in any year. Taken together, the trawl and seine data suggest that anchovy schools tend to favor certain specific locations over others; the determinants of such behavior are unknown.

Anchovies have been found to be impinged in small quantities (1 to 16 fish per day) on the New Haven Harbor traveling screens in every month except January; however, impingement is most consistent throughout the summer. Comparatively high rates of impingement (35 to 45 fish per day) were observed on the following dates: 12 August, 1975; 8 June, 1976; and 29 November, 1977. Observations similar to these have been reported for other Long Island Sound power plants (LILCO, 1978).

In Long Island Sound, Richards (1959) has indicated that spawning begins in early June and continues until early September, with the peak activity occurring in late July or early August. Eggs and larvae were identified from New Haven Harbor ichthyoplankton samples beginning in 1974. These data indicate local egg production to have begun as early as May (in 1976 and 1977) and that peak densities increased from 0.07 per m^3 in July 1974 to 113 per m^3 in July of 1977. At the same time peak larval densities have declined from 5 per m^3 in July 1974 to 0.02 per m^3 in October 1977. Notwithstanding the rather infre-

quent (monthly) sampling intervals, it appears qualitatively as though there has been a shift in the principal importance of New Haven Harbor regarding anchovy reproduction from nursery area to spawning area.

Ichthyoplankton data from other power plant locations (LILCO, 1974; NUSCO, 1977) indicate June and July to be the months of peak egg production. In 1976 peak densities ranged from a low of 2 eggs per m^3 , at Glenwood to a high of 19 m^3 at Millstone; in New Haven Harbor the 1976 peak value was 22 eggs per m^3 . The larvae, which were very scarce in 1976 (approximately 0.001 per m^3), were far more common at other Long Island Sound power plants; their densities ranged from a peak of 4400 per m^3 at Port Jefferson, to 14 per m^3 at Glenwood. Because peak larval abundance at Glenwood was greater than egg abundance, this might be construed as evidence to support the hypothesis that prime spawning and nursery areas may be spatially distinct for this species.

Atlantic Mackerel (Scomber scombrus)

According to Bigelow and Schroeder (1953) the Atlantic mackerel is one of the swiftest swimming species of open ocean fish. It is popular both as a commercial and sport fish. Mackerel are planktivorous, feeding on copepods, euphausiid shrimp, and other large planktonic crustacea (Bigelow and Schroeder, 1953). In winter, mackerel move out into deeper waters of the continental shelf, and return inshore in spring.

Mackerel are so constantly on the move that sampling methods used in the New Haven Harbor study would not be expected to catch a quantitative sample. The most effective commercial methods of catching this species are the purse seine, and gill nets (Bigelow and Schroeder, 1953). In the New Haven Harbor study, gill nets were by far the most successful (Figure 11-28), with no catch by beach seine. The greatest catch occurred in May 1975 when 122 fish (37 to 50 cm long) were recovered from gill nets at Station 19 (Figure 11-29). Only the outermost

$\theta, \overline{T}$ PREOPERATIONAL $0, \overline{T}$ OPERATIONAL / NO SAMPLE

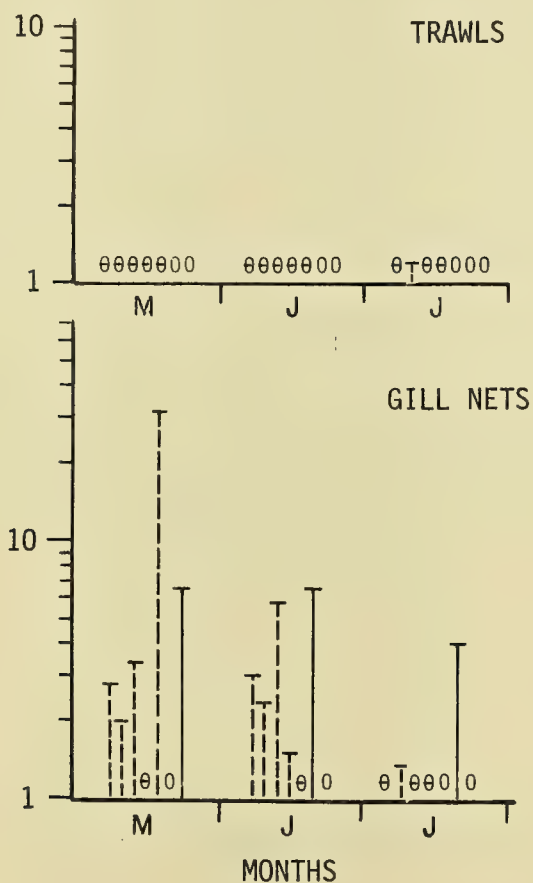


Figure 11-28. Monthly mean abundance of *Scomber scombrus* collected by gill net and otter trawl from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

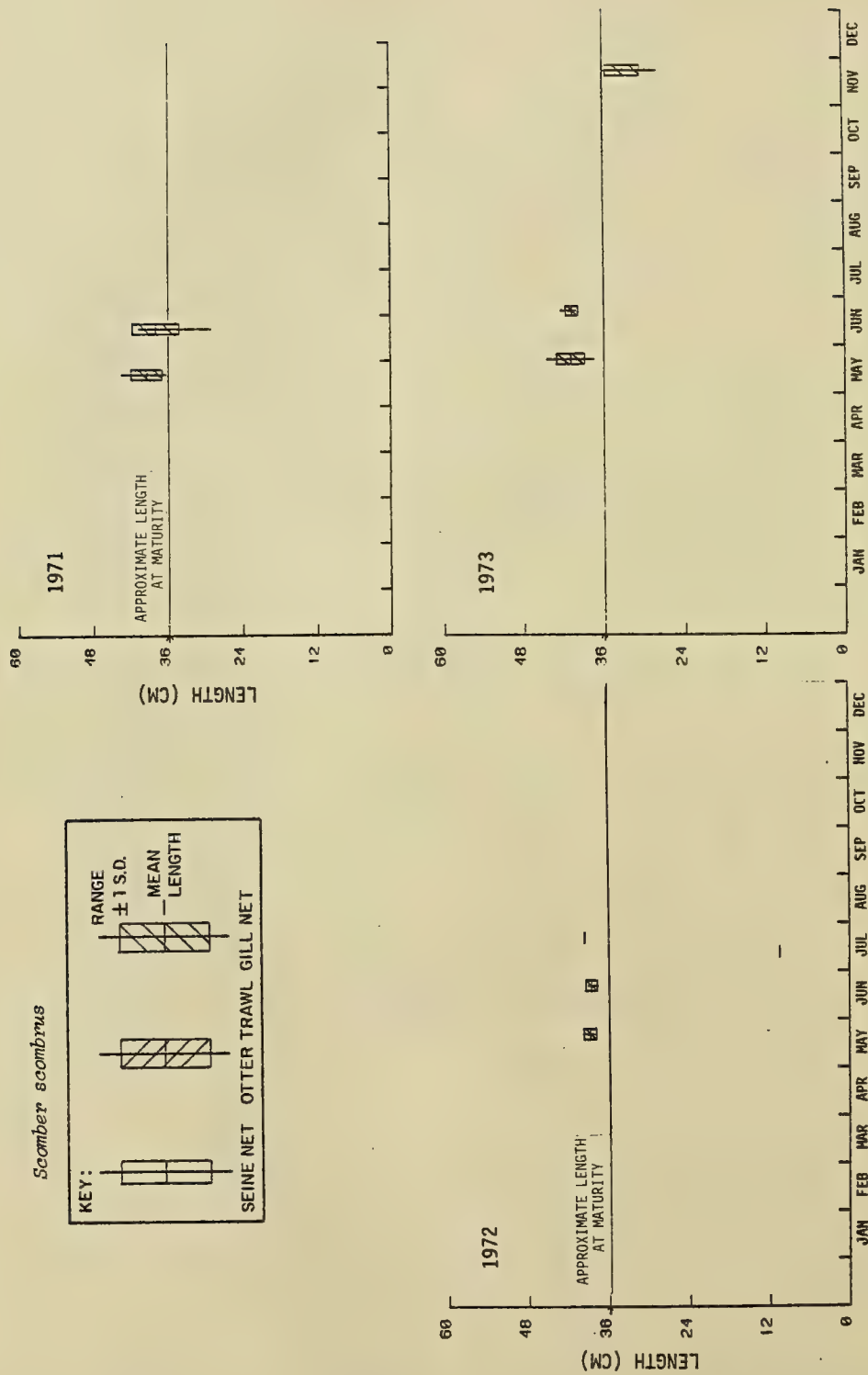


Figure 11-29. Total length (mean, range and std. dev.) of *Scomber scombrus* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

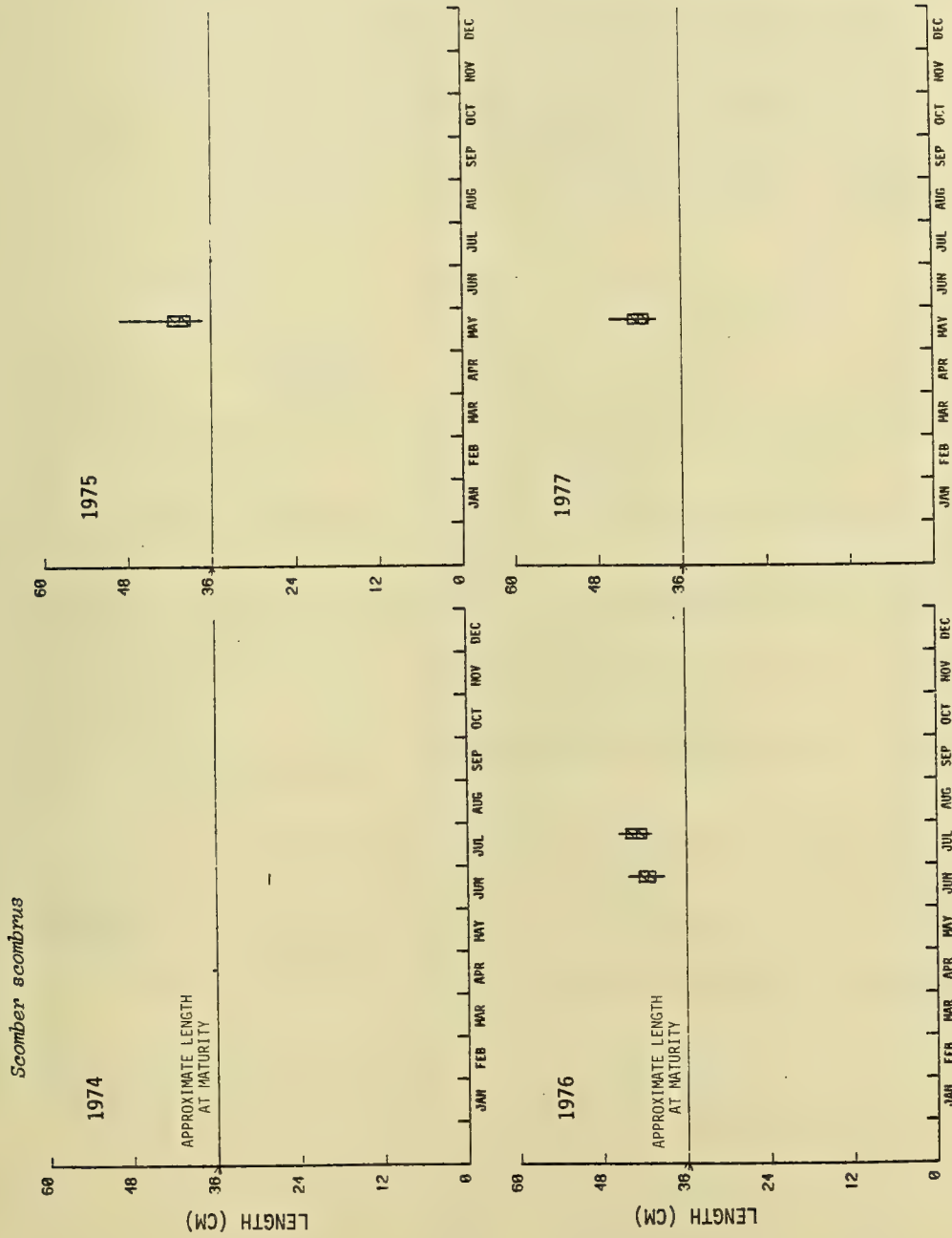


Figure 11-29. (Continued)

gill net stations (13 and 19) have taken more than 3 fish at any one time. Mackerel catches in New Haven Harbor have occurred exclusively from May through July.

The extremely low impingement rate for this species is also indicative of its swimming strength and low abundance in the harbor. Only one individual has ever been recovered from the New Haven Harbor Station traveling screens (22 June 1977). Similar impingement rates have been reported at other Long Island Sound power plants (NUSCO, 1977; LILCO, 1977; CLP, 1977).

"Mackerel ... shed their eggs wherever their wandering habits have chanced to lead them when the sexual products ripen" (Bigelow and Schroeder, 1953). A 0.85 kg female mackerel is capable of producing up to 546,000 eggs (Bigelow and Schroeder, 1953). Bigelow and Schroeder (1953) also stated that "...mackerel vary so widely in abundance over periods of years that the precise localities of greatest egg production may be expected to vary from year to year depending on local concentrations of fish." Such descriptions of mackerel life-history are consistent with the history of mackerel egg abundance in New Haven Harbor. In 1975, the average density during May, the peak month, was 13.30 eggs per m^3 . This contrasts sharply with peak densities recorded for 1976 (0.95 per m^3) and 1977 (1.50 per m^3). In 1976, peak mackerel-egg densities ranged from 3.60 to 17.50 per m^3 in the vicinity of other Long Island Sound power plants. It is also evident from Long Island Sound ichthyoplankton data that mackerel eggs may be expected to occur in substantial quantities in this region from May through June (NYOSL, 1974; NUSCO, 1977).

In contrast to the observed egg densities, mackerel larvae appear to be rather sparsely distributed in inshore waters. In New Haven Harbor, the maximum density encountered was 0.001 larva per m^3 (in May 1975). Among the 1976 Long Island Sound ichthyoplankton surveys reviewed, the highest larval density reported (for Millstone, in June) was 0.01 per m^3 (NUSCO, 1977).

Weakfish (Cynoscion regalis)

Weakfish and scup share nearly identical inshore-offshore and winter-summer migratory habits, as well as the tendency to school. The timing of spawning during the warmer months is also similar. Weakfish, also known as squeteague and grey sea trout, are an important food and game fish, popular particularly with anglers (Perlmutter, Miller and Poole, 1956). They are voracious feeders, consuming a wide variety of marine animals, including arthropods, molluscs, annelid worms, and vast quantities of other smaller fish (Stickney, Taylor and White, 1975; Chao and Musick, 1977).

During July-September New Haven Harbor surveys, juvenile weakfish (3 to 18 cm) were consistently caught by the hundreds in otter trawls, whereas adults (25 to 70 cm) have been captured, several fish at a time, mostly in gill nets (Figure 11-30). In 1971 and 1974, August otter trawl catches at Station 8 yielded 1200 and 2500 juveniles, respectively; in 1975, nearly 3000 juveniles were captured in August at Station 11 (Figure 11-31). Catches of both immature and mature weakfish have occurred exclusively from May through October in trawls and gill nets. Richards (1963) also took juvenile weakfish at her Station 3A (about 13 kn WSW of New Haven Harbor) in September and October 1956.

Impingement of weakfish on New Haven Harbor Station traveling screens has been sporadic. Two incidents all involving juvenile fish (7 to 18 cm), have occurred; the first was in August 1976 and the second in October 1977* (Figure 11-32). Fewer weakfish were caught in samples from Niantic Bay (NUSCO, 1977), Shoreham, NY (NYOSL, 1974) and the Mystic River, CT estuary (Pearcy and Richards, 1962) than have been captured in New Haven. The magnitude of difference in weakfish abundance between New Haven Harbor and other Long Island Sound areas cannot be precisely determined because of differences in sampling techniques and schedules, but the mean weakfish catch per hour of trawling effort (all months and

* Although the study period closed as of October 1977 weakfish continued to be impinged through December 1977, at an average daily rate of 58 in November and 29 in December.

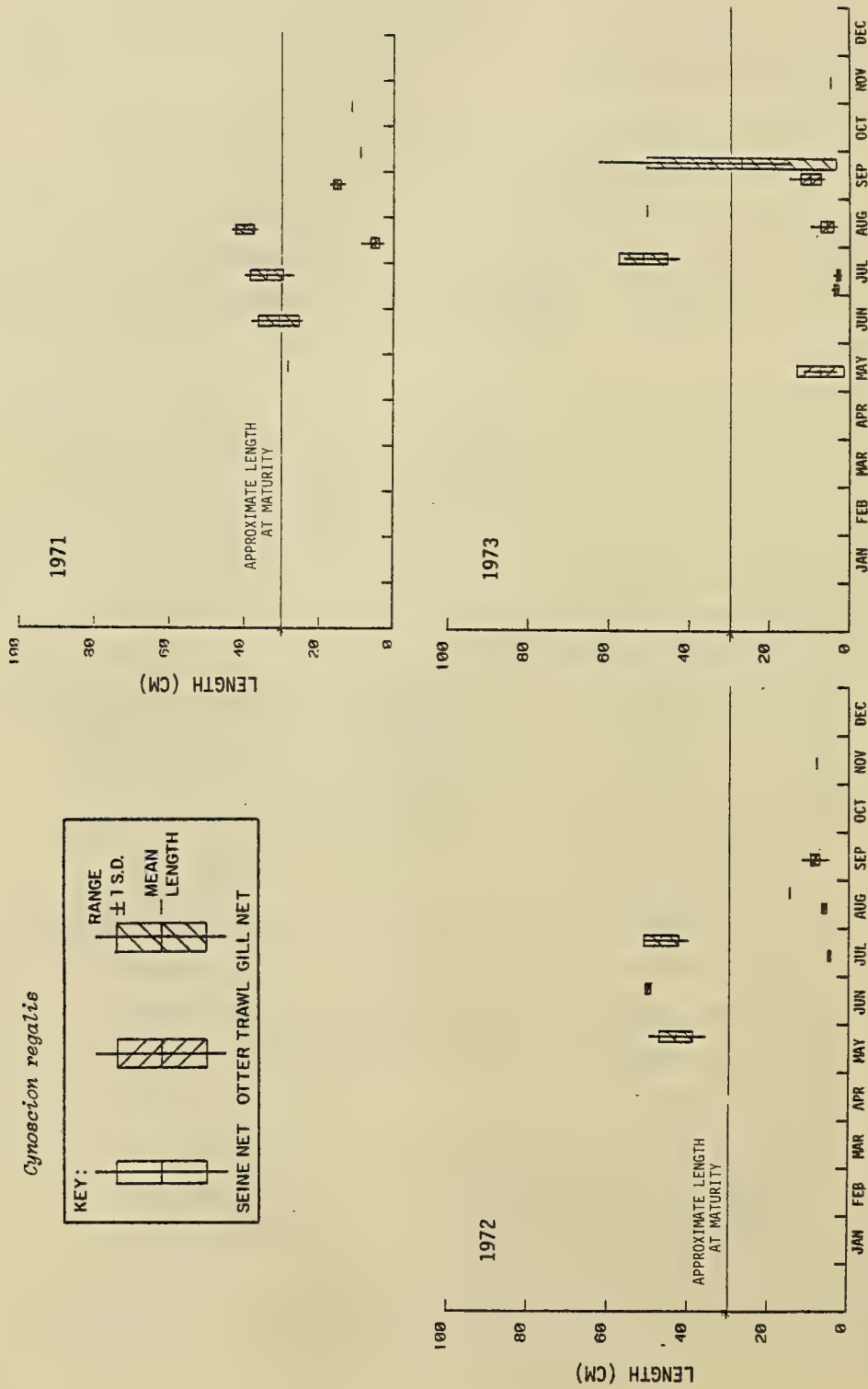


Figure 11-30. Total length (mean, range and std. dev.) of *Cynoscion regalis* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1979. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

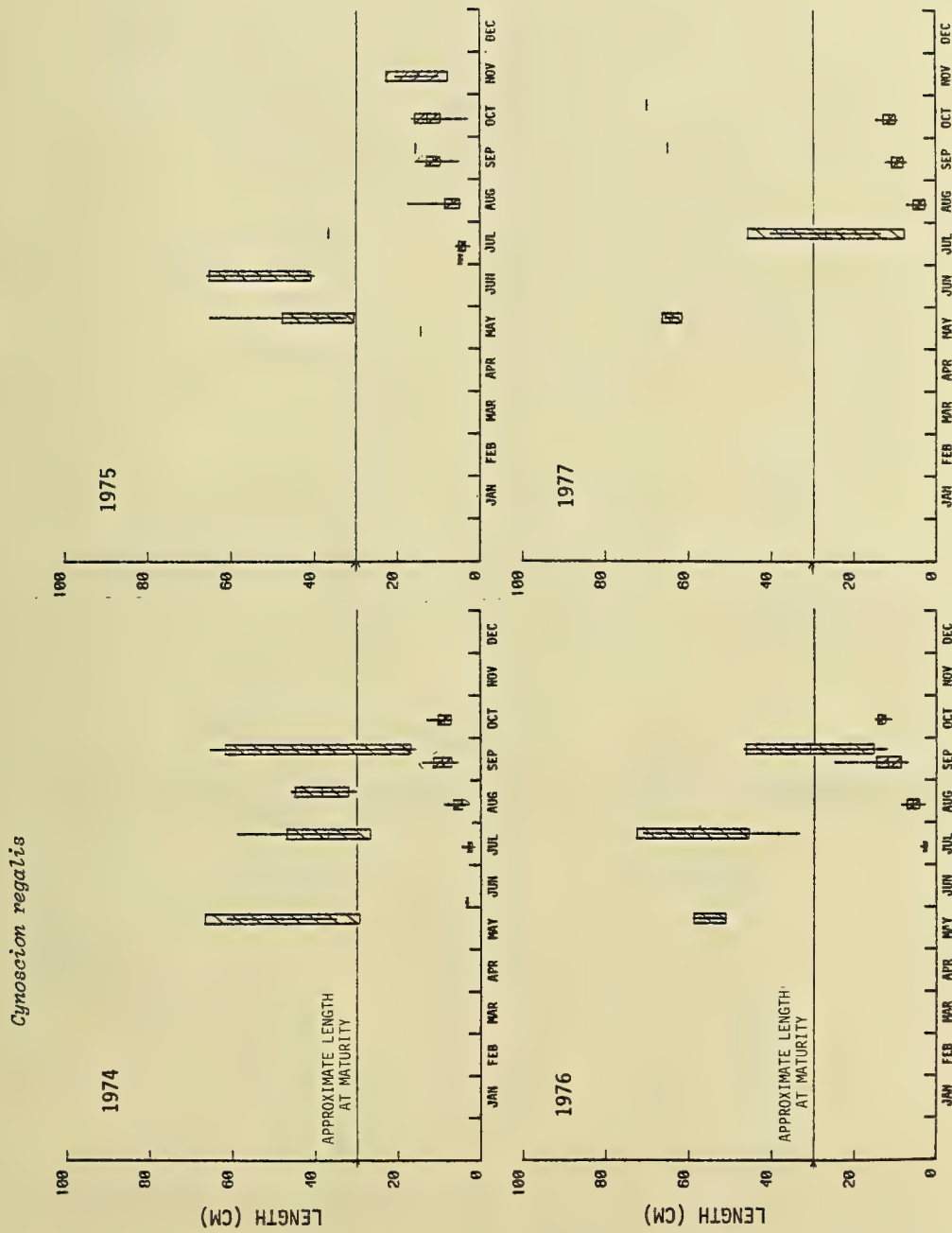


Figure 11-30. (Continued)

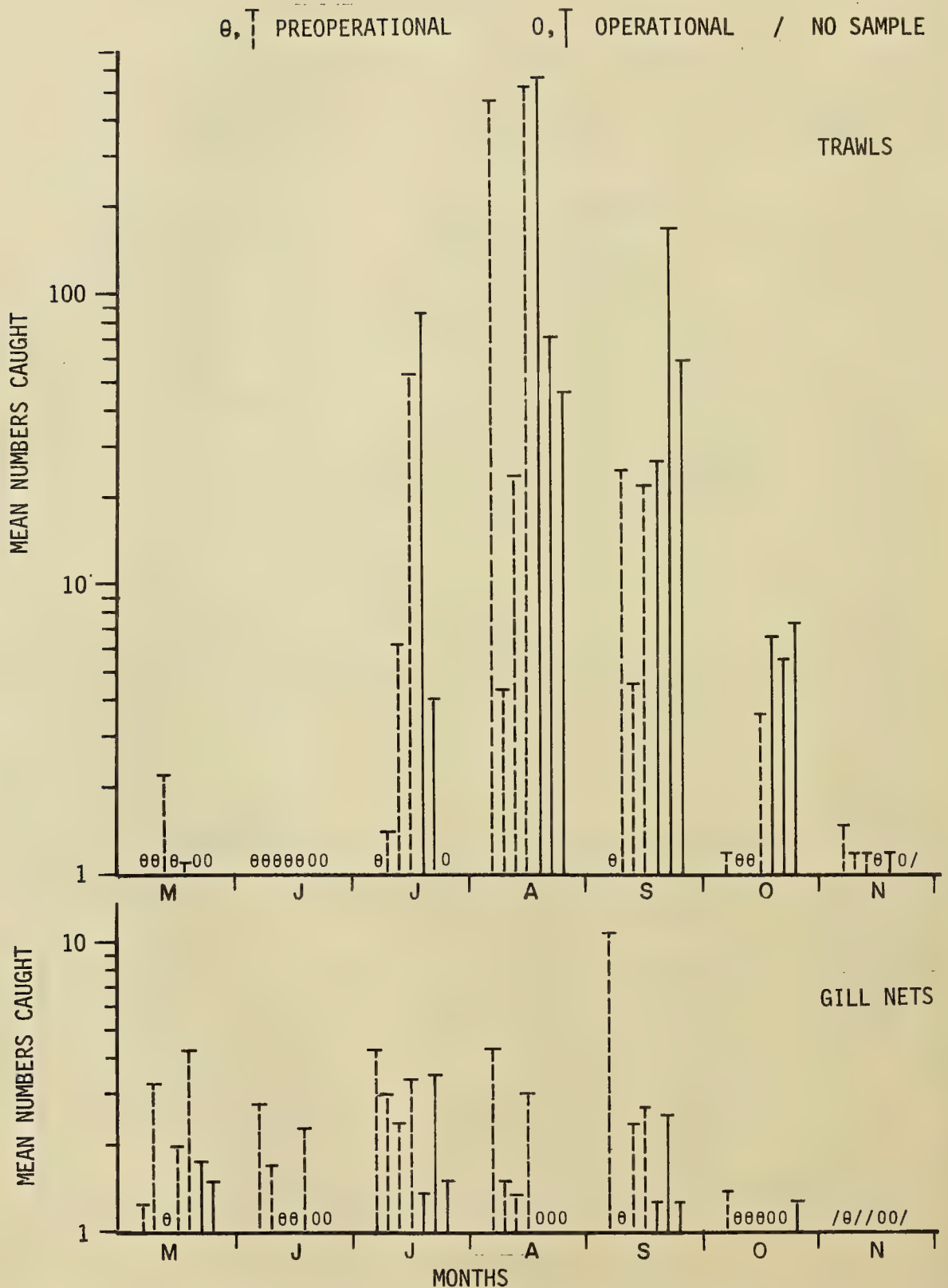


Figure 11-31. Monthly mean abundance of *Cynoscion regalis* collected by gill net and otter trawl from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

stations) in New Haven was 174; the maximum at Shoreham was 140 and the mean was <30 weakfish/hr effort. One or more orders of magnitude greater impingement may be directly correlated with greater density in New Haven Harbor.

In New Haven Harbor, weakfish larval densities consistently peaked during the month of July. The most abundant collections (0.22 larvae per m³) occurred in July 1976, followed closely by the numbers collected in July 1977 (0.14 per m³). These densities are also 5 to 10 times as high as densities recorded near other Long Island Sound power plants, (NUSCO, 1977, 1978; NYOSL, 1974) and are comparable to those observed for Long Island Sound by Wheatland (1956).

Bluefish (Pomatomus saltatrix)

The bluefish is a predacious open-water species widely distributed in warm seas (temperature greater than 15°C). The adults are highly regarded by sport fishermen for their ferocity and the excellent eating quality of the flesh (Bigelow and Schroeder, 1953). Schools of bluefish, sometimes consisting of more than a thousand individuals, are well known for their frenzied attacks on schools of prey species, such as mackerel, menhaden, herring, or alewives. The juveniles (6 to 25 cm) called "snappers", feed on copepods, crustacean and mollusc larvae, and on fish smaller than themselves. Snappers are rarely found far from shore and often seek their prey in estuaries. They remain near the coast as they retreat to warmer water southward in the fall, whereas the adults over 45 cm move offshore to stay with warmer water (Lund and Maltezos, 1970).

In the New Haven Harbor Studies, snappers have been collected primarily by gill nets and beach seines (Figure 11-33). Peak catches have occurred in July, August, September and October; no bluefish have been taken from December through April. Occasionally, one or two adult bluefish have been taken in gill net catches (Figure 11-34). Warfel and

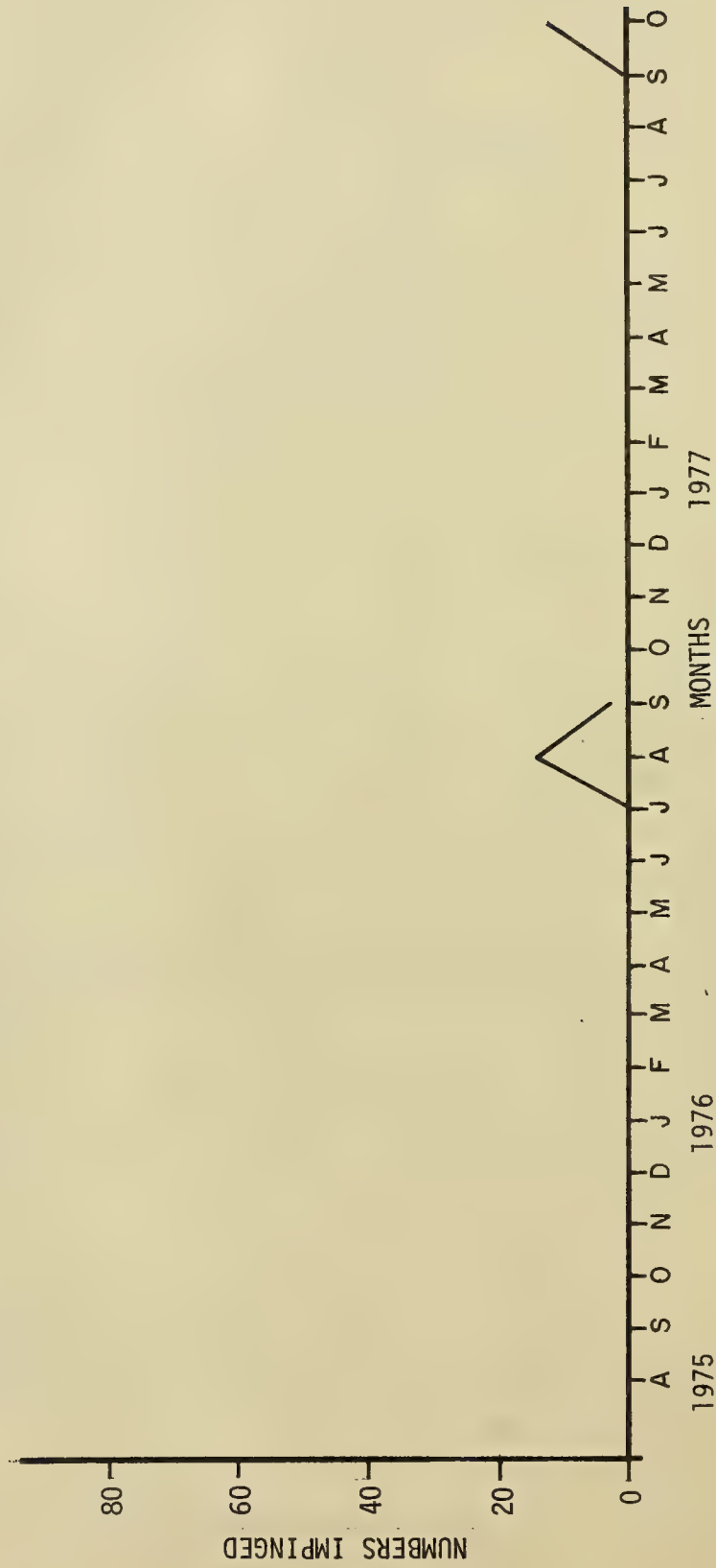


Figure 11-32. Mean daily impingement of weakfish (*Cynoscion regalis*) by month at the New Haven Harbor Station; August 1975 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

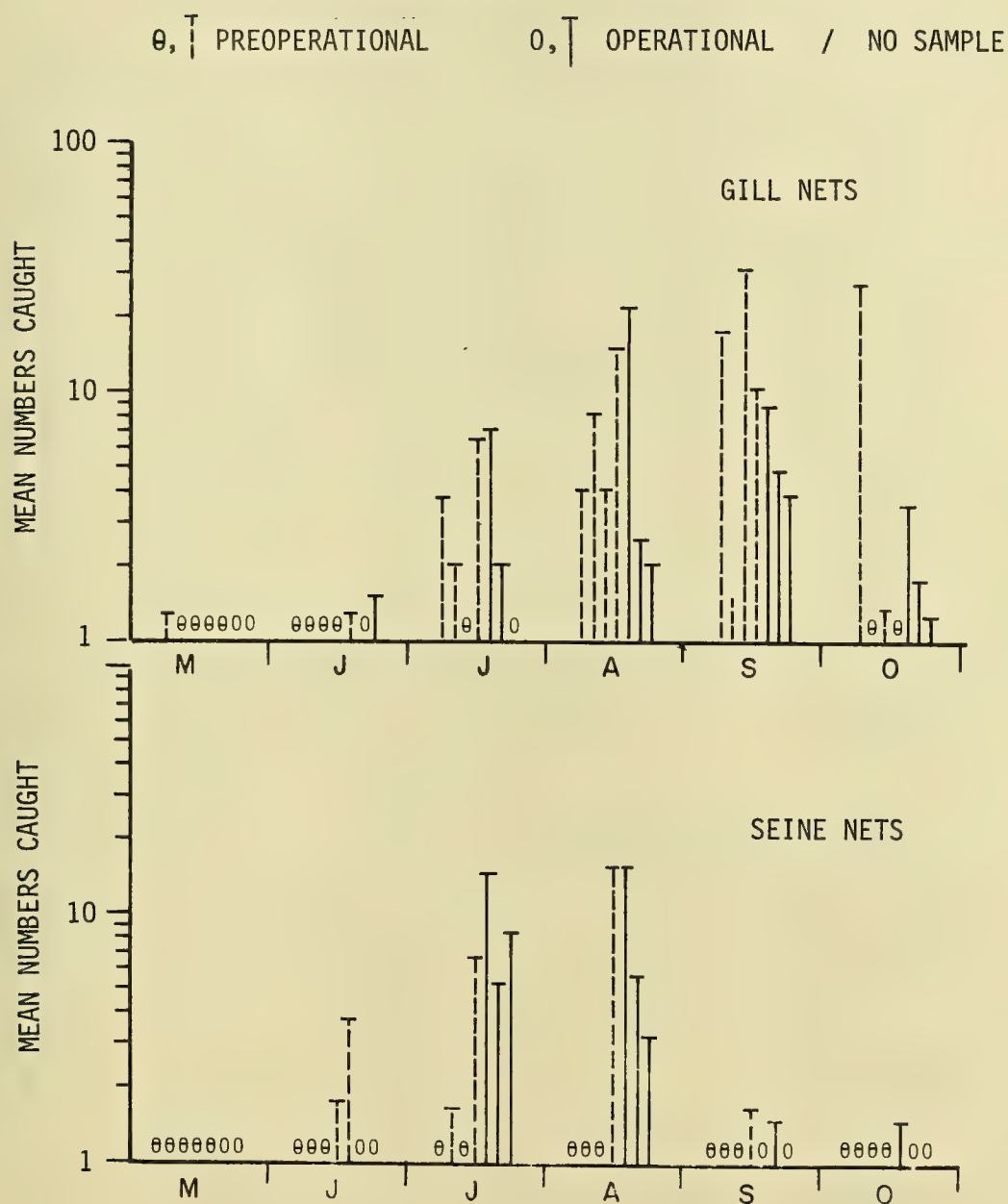


Figure 11-33. Monthly mean abundance of *Pomatomus saltatrix* collected by seine and gill net from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

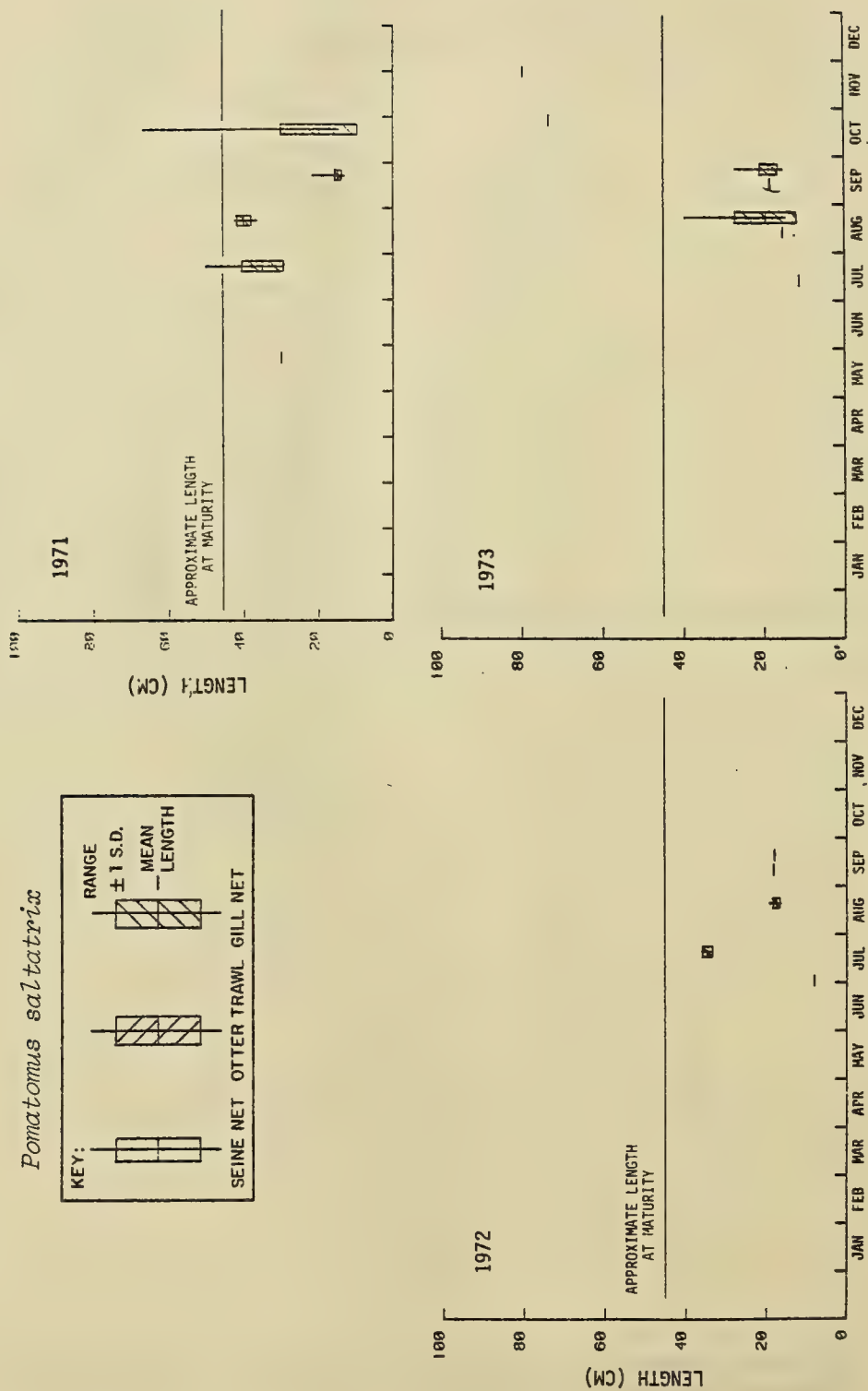


Figure 11-34. Total length (mean, range and std. dev.) of *Pomatomus saltatrix* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1979. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued

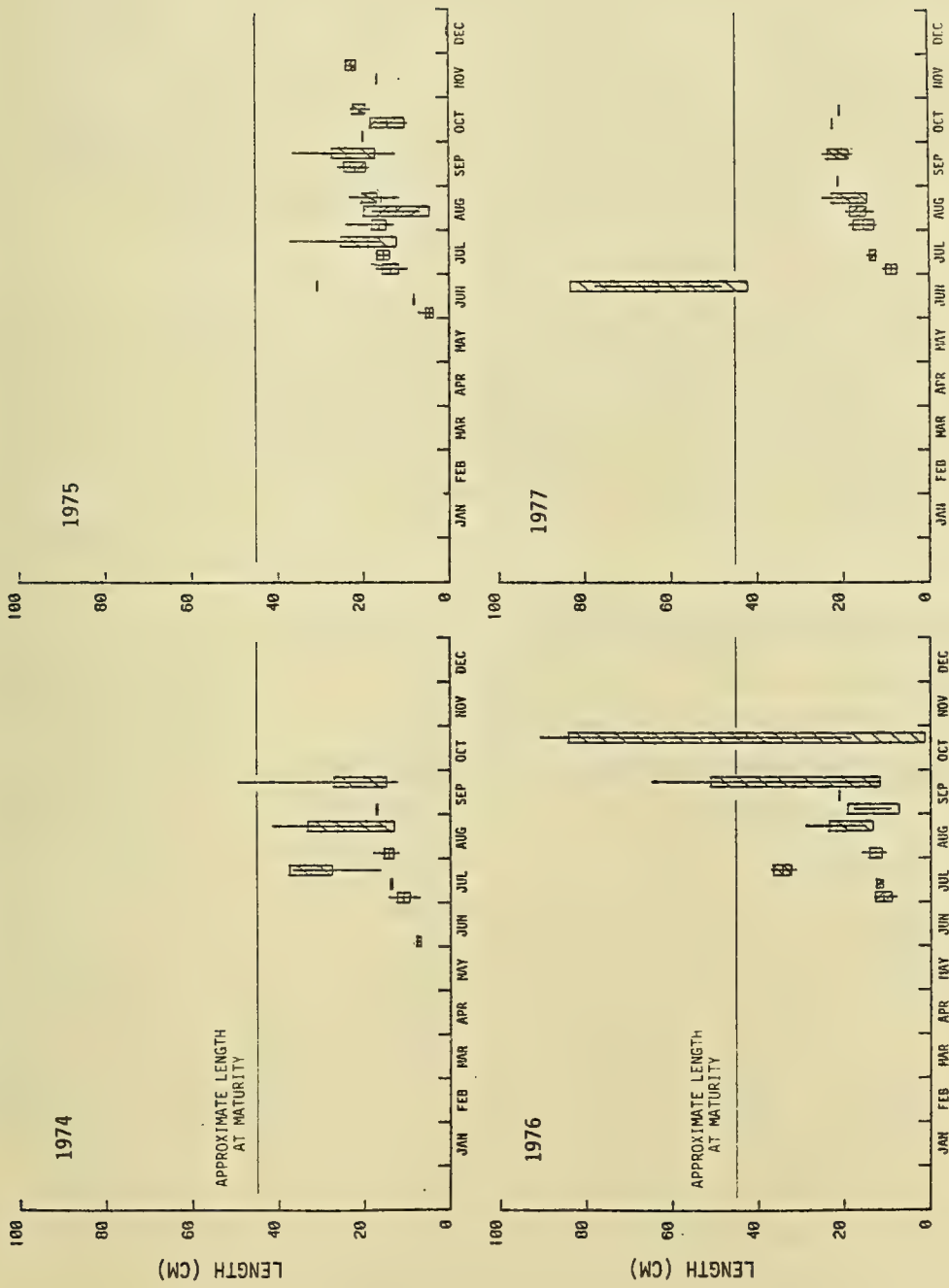
Pomatomus saltatrix

Figure 11-34. (Continued)

Merriman (1944) caught small numbers of snappers in Morris Cove, New Haven in October 1942.

Impingement rates at New Haven Harbor Station are low (the highest number recorded is only 9 fish per day) and involve only the snappers. Traveling screen collections have consistently yielded several snappers each August since 1975, but rarely have any of these young bluefish been observed on the screens in any other month. Judging from the records for other Long Island Sound power plants, (CLP, 1976; NUSCO, 1977), the snapper impingement rate at New Haven Harbor Station is typical.

Spawning occurs from late spring through August in the surface waters of the outer continental shelf (Dauck *et al.*, 1966; Norcross *et al.*, 1974). There are no records of the eggs and larvae occurring in ichthyoplankton collections from Long Island Sound.

Striped Bass (Morone saxatilis)

The striped bass is anadromous and feeds most heavily on amphipods, mysids and bay anchovies (Schaefer, 1978). Seaward distribution is generally restricted to within 4 or 5 miles of the coast except when migrating (Merriman, 1941; Bigelow and Schroeder, 1953). Migrating schools are comprised of fish 2 years of age and older. The seasonal movements of these older, larger (>16 cm) fish have been documented, with regard to Long Island Sound and vicinity by Austin and Custer (1977): along the Atlantic coast, between Virginia and Massachusetts, there is a general northward migration in the spring. Schools of striped bass enter Long Island Sound from either end, but primarily from the eastern end. In the fall, stripers returning south from Massachusetts and Rhode Island move into Long Island Sound from the eastern end. This is followed by movement across the Sound, from central Connecticut to the Long Island side. The principal route of migra-

tion southward to winter quarters off Virginia and Chesapeake Bay, is via the eastern opening of Long Island Sound.

Some fish, particularly the younger ones, over-winter in the Hudson River and other deeper estuaries north of Virginia where the deeper waters do not become extremely cold. In order to avoid the extreme cold of winter, these fish are sometimes attracted to the thermal plumes of power plants; young striped bass have been observed at the Northport Generating Station throughout the winter.

In New Haven Harbor adult striped bass (23 to 57 cm) have been taken only from April through November, primarily by gill net (Figure 11-35). Largest catches occurred in 1972 when 3 to 7 fish were caught per net haul in May and June (Figure 11-36). Since then, nets have taken no more than a single individual at a time, except when 2 two-year olds (approximately 15 cm long) were in the otter trawl catch from September 1976.

There are no records of any striped bass being impinged on New Haven Harbor Station traveling screens. It is unlikely that adults of this species, which are extremely powerful swimmers, would have any difficulty avoiding the intake of a power plant with low intake velocities.

With the exception of the Hudson River, there is no evidence that this species spawns in Long Island Sound tributaries (Clark, 1968). In none of the Long Island Sound power plant studies reviewed for this report were there any records of striped bass eggs or larvae in the ichthyoplankton collections, nor were there any eggs or larvae collected from New Haven Harbor during the seven years of ichthyoplankton monitoring.

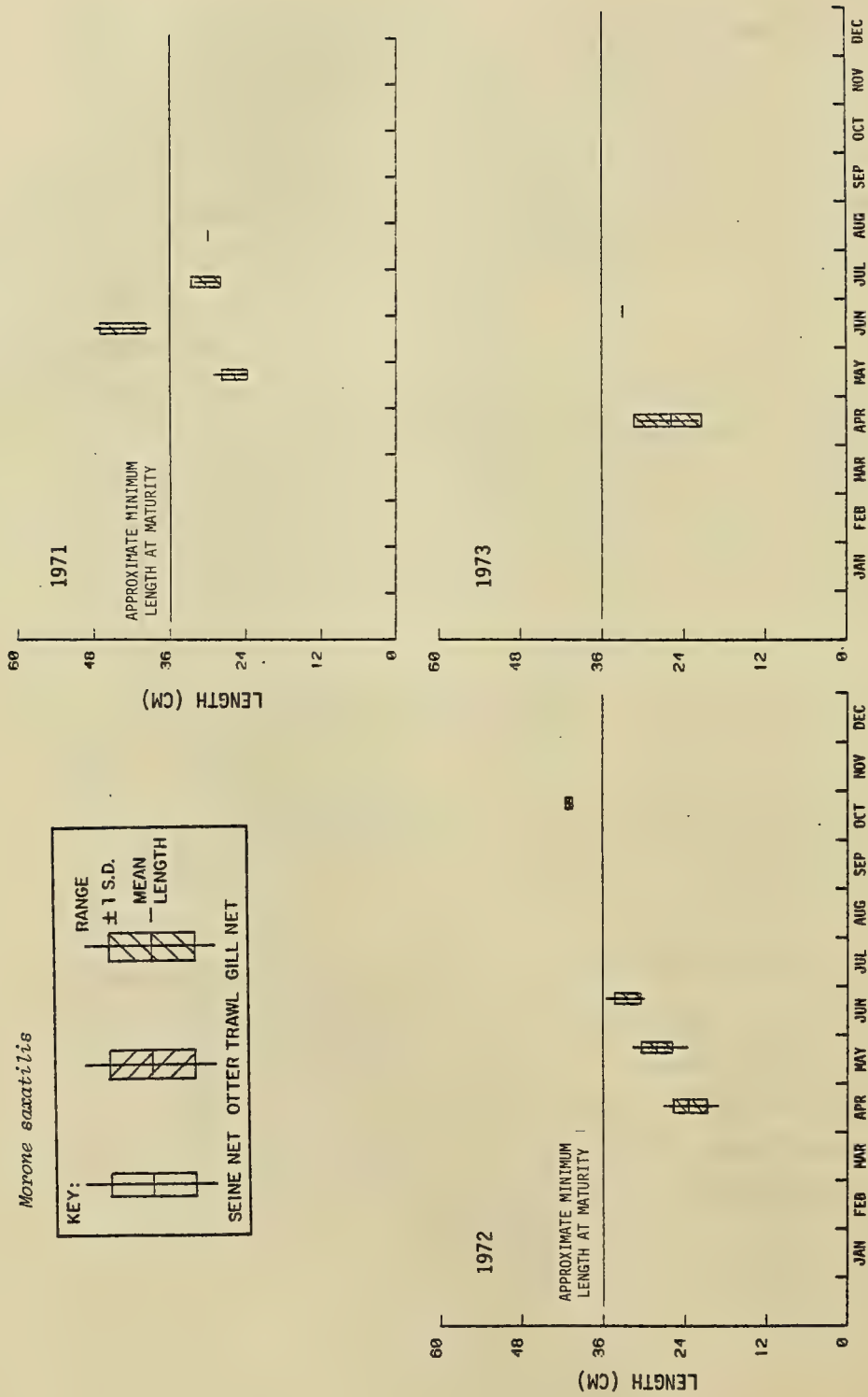


Figure 11-35. Total length (mean, range and std. dev.) of *Morone saxatilis* captured by various sampling devices in New Haven Harbor, Connecticut, from May 1971 through October 1979. New Haven Harbor Ecological Studies Summary Report, 1979.

Continued



Figure 11-35. (Continued)

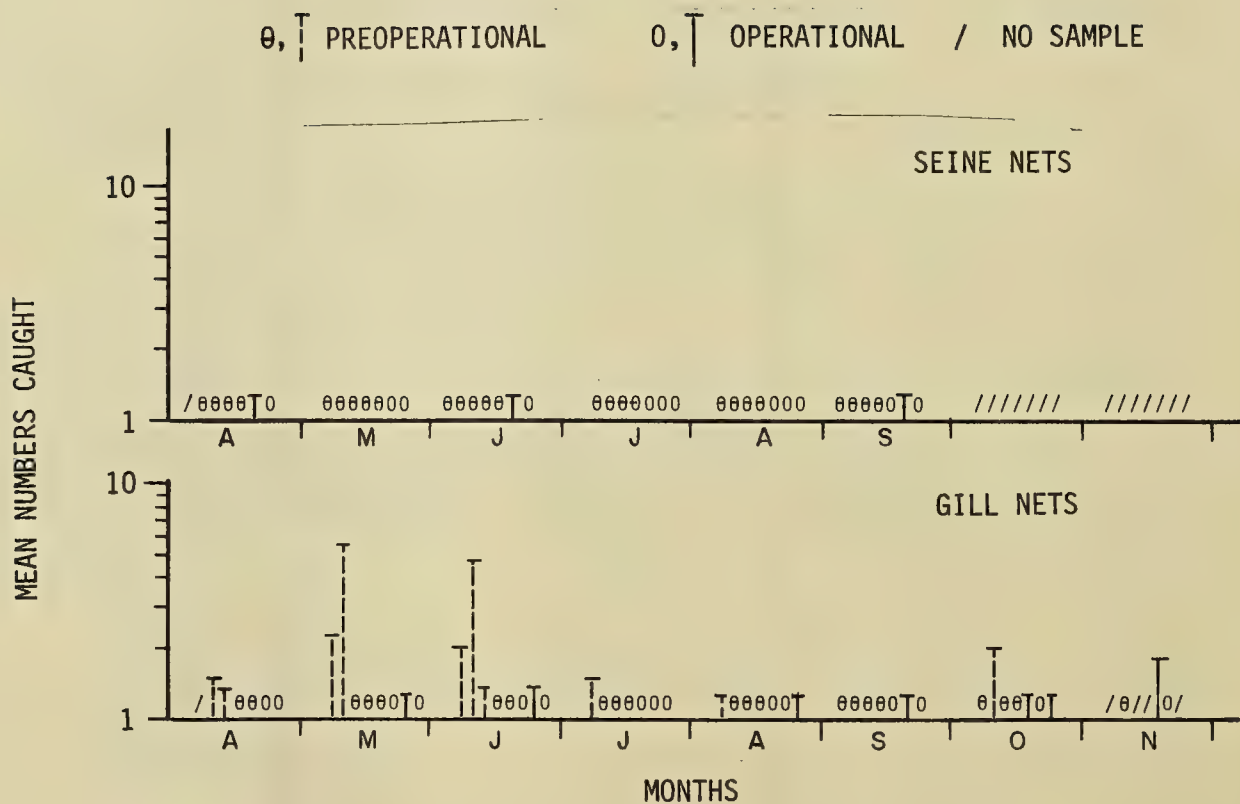


Figure 11-36. Monthly mean abundance of *Morone saxatilis* collected by seine and gill net from May 1971 through October 1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Summary of Representative Species

Demersal Residents

Winter Flounder

The winter flounder is regionally important as a commercial and recreational species, although there is virtually no exploitation of this species in New Haven Harbor. The importance of this species to the harbor lies in its roles in the food web, both as potential prey for summer flounder, gulls, mergansers and cormorants, as well as a predator on the zooplankton, and benthic epifauna and infauna. Because winter flounder is an abundant, resident species, its trophic importance cannot be overemphasized. New Haven Harbor is apparently not a major spawning ground or adult feeding ground, but has some importance as a nursery where winter flounder spend their first and second years.

Windowpane

The windowpane is an abundant resident species of no present commercial or recreational significance, although Moore (1947) found potential commercial value for the windowpane. Windowpanes spawn, feed and mature in New Haven Harbor, apparently completing their entire life cycle there. This species is probably a significant predator on the zooplankton, mysid and sand shrimp populations in the harbor. Juvenile windowpanes probably are preyed upon by the same predators as winter flounder. New Haven Harbor's windowpane population appears to be similar in density to other suitable coastal areas in Long Island Sound.

Cunner

Cunner, although year-round residents of New Haven Harbor, are of ecological importance only during spring, summer and fall due to

their winter dormancy. Because of their choice of habitat, the adults are relatively safe from predation as well as from sampling efforts. As a result, we believe that their actual abundance exceeds our estimates and that this species is abundant among the piers, groins and breakwaters of New Haven Harbor. Cunner feed heavily on bivalves, barnacles and other benthos; probably on *Mytilus edulis* and *Balanus* spp. in New Haven. The cunner is of little commercial or sport value, but is probably of great ecological significance due to its substantial contribution to the ichthyoplankton, where it is second in abundance only to the bay anchovy. These eggs have a high natural mortality in transition to larvae, probably due to predation. New Haven Harbor provides neither particularly extensive nor unique habitat for cunner.

Demersal Migrants

Scup

Second to winter flounder, the scup is important in the Long Island Sound commercial and sport fishery. Scup winter offshore and spawn inshore in the spring and summer; it does not appear that spawning occurs regularly near New Haven or to the west. Adults are uncommon in New Haven; utilization of the harbor appears to be almost exclusively as a nursery for young-of-the-year and yearling fishes. Since even this utilization is inconsistent from year to year, it is apparent that New Haven is not a critical habitat for Long Island Sound scup populations. The occasional presence of numerous young scup, however, may take a heavy toll on the benthic infauna, *Neomysis* and *Crangon* populations, and introduces competition for prey with the indigenous winter flounder and windowpane populations.

Summer Flounder

Summer flounder spawn and overwinter in deeper, offshore waters, coming inshore in the warmer months to feed on *Neomysis*, *Crangon* and juvenile flatfishes. The adults are the subject of commercial and sport fishing where abundant. Summer flounder are not sufficiently abundant in New Haven Harbor to be important as predators or as prey to fishermen.

*Pelagic Planktivores**Atlantic Herring*

The Atlantic herring is the only winter migrant species of importance in New Haven; adults are present from October through June, and young-of-the-year are abundant during May and June. Herring are not generally present in commercial quantities in Long Island Sound and have no sport value. Atlantic herring are probably not simultaneously present in New Haven with species that prey upon them, with the exception of bluefish. The food of the herring in New Haven probably consists of mysids and copepods, and these food species might be heavily impacted by the sporadic presence of schools of herring in the harbor. In the perspective of the herring populations of the New England coast, New Haven Harbor is an occasional feeding and nursery ground for a small fraction of the Long Island Sound contingent.

Menhaden

Menhaden are summer migrants to New Haven Harbor; they overlap slightly with the Atlantic herring, arriving in April or May and remaining through October. Menhaden are of commercial value, sought for processing into fish meal and oil. They are abundant as adults, juveniles and larvae, although they are not believed to spawn in estuaries.

New Haven Harbor is affected by menhaden feeding; they travel in dense schools filtering phytoplankton and zooplankton from the water, their large numbers often altering water quality (reducing dissolved oxygen, increasing ammonia concentrations) by their physiological processes. Abundance of adult bluefish in the harbor may be directly related to the abundance of this prey species. Harbor water quality is sufficiently poor to cause or enhance mass mortalities of menhaden, which may be due to excessive temperature or industrial pollutants and/or low dissolved oxygen concentrations. These adverse conditions increase predation success by the bluefish and impingement by New Haven Harbor Station. As with Atlantic herring, New Haven Harbor is important only to a small fraction of the Long Island Sound contingent of this widespread and abundant species.

Alewife

A relatively small number of alewives probably ascend the tributary streams of New Haven Harbor to spawn in the spring. The abundance of this species is so low as to preclude substantial trophic importance. Alewives utilize New Haven Harbor as a zone of passage to their spawning grounds. In comparison with the rest of Long Island Sound, New Haven tributaries are of no quantitative significance in alewife reproduction.

Blueback Herring

Bluebacks, like alewives, may breed in New Haven tributaries, but do not do so in important quantities. Also, like alewives, they are not significant in food webs because of their relative scarcity.

Rainbow Smelt

Like the alewife and blueback, smelt are anadromous, spawning in fresh water. Smelt apparently utilized New Haven Harbor's tributaries to a very limited extent, except in 1973 when large numbers were caught. When abundant, smelt provide good forage for striped bass, shad, bluefish, and weakfish, and might be expected to have some impact on the zooplankton species on which they feed.

American Shad

The American shad is an anadromous, planktivorous species which spawns in the freshwater reaches of major streams and feeds in marine waters on copepods such as *Acartia* and *Temora*. Occasional catches indicate that a minor spawning run may possibly occur in the Quinnipiac River; adults were caught in May and June 1976 and juveniles have been caught irregularly in October and November. An alternative hypothesis suggests that these fish were enroute to or from the Connecticut River, which supports an important shad run. The few individuals caught in New Haven indicate little or no importance for the harbor and its tributaries for this species.

Bay Anchovy

Bay anchovies are summer migrants that are routinely abundant in New Haven Harbor between July and October. Anchovies spawn and mature in New Haven Harbor during the summer months and depart in the fall. The species is of no commercial significance, and is of concern to sport fishermen only indirectly, as anchovy schools provide a sort of "living chum" for such recreational species as weakfish, striped bass, and bluefish. Because of their abundance, anchovies probably have a major influence on the zooplankton populations on which they feed.

Atlantic Mackerel

Mackerel are important sport fish as well as having commercial value. Schools of mackerel are nomadic, perhaps following abundant food sources. Mackerel schools occasionally enter New Haven Harbor during May, June or July, and, as is their habit, may spawn at that time. The small schools which apparently occur in the harbor and the relatively short time that they are present limits the importance of this species to the harbor food chain.

*Pelagic Piscivores**Weakfish*

Weakfish run into New Haven Harbor to spawn and feed from May through October. The Harbor serves as feeding, spawning and nursery ground to a large contingent of this excellent recreational species. Large adults probably remain in the harbor to feed on the abundant bay anchovy and Crangon, while the numerous juveniles feed on anchovy eggs, larvae and other zooplankton. This species is, both by abundance and appetite, exceptionally important to the harbor finfish assemblage and food web. There are indications that New Haven Harbor may be one of the best weakfish nursery grounds in the Long Island Sound area. There is little sport fishing effort for this species in New Haven Harbor; striped bass and bluefish are the primary objects of the sport fishery in which weakfish are a welcome catch.

Bluefish

Like weakfish, bluefish utilize New Haven Harbor only during the summer (June-October). Unlike the weakfish, they use the estuary solely as a feeding and nursery ground. Occasional adults and schools of juveniles ("snappers") run into the harbor during the summer and fall

to feed on adult and juvenile menhaden and possibly other species. The harbor is a good but unexceptional feeding ground for this voracious predator, and there is in turn some substantial sport fish effort for snappers and adults.

Striped Bass

The anadromous striped bass is much sought after and occasionally caught in New Haven Harbor's sport fishery. Striped bass do not breed in the estuary or its tributaries; rather, the estuary serves as a feeding ground to small numbers of stray bass that wander into New Haven Harbor in April, May or June, or to stragglers on the southward migration in October or November.

ANALYSIS OF IMPACTS

There are essentially three ways in which the operation of steam electric-generating stations, including NHHS, may directly impact species of finfish that frequent the waters used for condenser cooling:

1. Entrainment of planktonic eggs and larvae through the cooling water system;
2. Entrapment and impingement of adults and juveniles at the cooling water intake; and,
3. Encounter at all life-history stages with heated waters.

Indirect impacts on finfish populations occur as results of direct impacts on other ecosystem components or other finfish: for instance, an indirect impact on predator species (prey scarcity) may result if prey species are directly impacted by entrainment.

Direct impacts may be measured by various means: entrainment effects may be directly measured, modeled from design specifications and species tolerance data, or inferred from monitoring of the base population. Impingement is most frequently measured by counts and measurements of impinged organisms, while thermal effects are usually measured by before/after monitoring of the receiving waters to detect changes in patterns of size, abundance or distribution concomitant with changes in operational status of the plant. In New Haven Harbor, long-term pre-operational and operational monitoring and direct measures of impingement were chosen to assess entrainment, impingement and thermal effects. Study emphasis has been on monitoring patterns of size, abundance and distribution before and after New Haven Harbor Station commenced operation; we believe that the basic concern of environmental protection is non-interference with natural population parameters. As Enright (1974) indicates, measurements of impact such as numbers of various life-history stages killed per year are relevant only insofar as they can be placed in the context of a decision as to whether or not the dynamic equilibrium of a species or assemblage of species has been significantly altered by the impact. Impacts were assessed on this basis.

Specifically, patterns of abundance, size and distribution observed before plant operations commenced were compared with patterns found since start-up in July 1975. Differences observed were evaluated in terms of the probability of a causal relationship between plant operations and observed changes. Probability of causality was estimated on the bases of known mechanisms of impact (heat load on the harbor, volumes of water entrained, numbers of fishes impinged), established natural variability, and observed influences on the harbor unrelated to plant operations but unique to post start-up monitoring (unusual weather, dredging, oil spills, etc.).

In order to evaluate the impacts on finfish populations of other generating station operations (Hess, Sissenwine and Saila, 1975; Saila, 1976; NUSCO, 1977; Stone and Webster Engineering Corporation,

1975), population simulation models were constructed for population dynamics of winter flounder and menhaden subject to plant-induced mortalities. We did not construct similar models because we felt that to make the following assumptions was inadequate and inappropriate in the case of New Haven Harbor:

- 1) The area modeled represents a discrete population, subject to limited immigration or emigration of any life-history stages;
- 2) The base population of adults and potential recruits may be adequately estimated by either:
 - a) use of published density estimates for other areas;
 - b) application of trawl data to arbitrarily defined areas without verification that stations trawled are representative of the areas defined;
 - c) limited, size-selective mark and recapture studies.
- 3) Natural and fishing mortality rates may be chosen from published estimates from locales outside the study area.

We believe that there is no discrete (distinguishable as separate from Long Island Sound populations) resident population of finfish in New Haven Harbor. For most species, the harbor is apparently an "importer" of finfish eggs, larvae, and possibly juveniles, and an "exporter" of juvenile, pre-adult or adult fish. The importance of the harbor lies not in its instantaneous population but in its use as a nursery. In such a case, to describe a discrete, steady-state population structure by a mathematical model would be indefensible.

Because of the high short-term spatial and temporal variability in density and distribution of many finfish species, we would be hesitant to rely on population estimates generated by use of trawl catch.

Furthermore, published values for other estuaries have no obvious bearing on a large, nutrient-rich degraded estuary such as New Haven. Mark-and-recapture studies are inappropriate because of the small size of fish captured, implying probable high tag-mortality that would inflate estimated emigration rates.

Published natural and fishing mortality rates probably do not apply in New Haven Harbor; natural mortality must include (for our purposes) mortalities due to disease, starvation, predation, and impacts associated with other industrial and municipal discharges to the harbor. In light of the possible magnitude of these factors it would be unrealistic to assume natural mortality rates in such a stressed environment to be similar to those determined in relatively pristine locales. Fishing mortality would not apply to the fish characteristic of New Haven, which are either locally non-commercial, non-sport species (menhaden) or are uncommon in size-classes desirable in commercial or sport markets (winter flounder).

In conclusion, we question the applicability and accuracy of modeling techniques that utilize unverified estimates of initial population, mortality, fecundity and other parameters critical to the results of the simulation. We prefer, in the absence of verified, site-specific estimates of these parameters, to restrict our analysis to gross comparisons of preoperational vs. operational species abundance as reflected by catch.

Passage through the Cooling Water System: Pumped Entrainment

Recent studies of fish egg and larval entrainment mortalities (Cannon et al., 1978) have indicated survival rates considerably higher than had been determined from earlier efforts (Marcy, 1975, 1976), at least at water temperatures below lethal thermal thresholds (generally ca. 30°C).

Evaluating total entrainment losses (cropping) under worst-case conditions, i.e., assuming 100% mortality, and using seasonally averaged egg and larval densities, reported for the years of maximum abundance, the impact in terms of numbers of individuals killed may be roughly estimated by taking the "worst case" conditions and multiplying the average densities by the demand of the cooling water intake for the entire period of egg or larvae occurrence. Results of such computations are shown for the 16 representative species in Table 11-3.

Estimates of the number of eggs and larvae entrained during a year of maximum abundance range from several tens of thousands to several hundred million, depending on the species in question. Though any attempt to interpret such losses in terms of the ultimate impact on the adult population is imprecise, it is useful to compare these approximate entrainment losses with those that might be expected to result from natural causes -- starvation, predation, and disease. Leggett (1969) estimated a 0.001% survival rate from egg to adult for the American shad on the Connecticut River; similarly, Kissil (1974) reported 0.004% survival from eggs to sea-running juvenile alewives. Winter flounder, which at about 8C require 49 days to develop from egg to juvenile (Laurence, 1975) undergo natural mortality of 20% per day as early larvae and 4% per day as post larvae (Pearcy, 1962). Percy (1962) estimated total mortality for larval and juvenile stages of winter flounder at 99.98-99.99%. If such survival ratios are generally applicable to other species, then the loss of 10 million eggs through passage through a power plant cooling water system would be equivalent to the loss of 10 to 14 thousand juvenile to adult fish.

Jones and Hall (1973) developed a computer simulation model for the growth and survival of haddock (*Melanogrammus aeglefinus*) larvae which indicated a mortality rate of 10% per day. A comparable modeling effort by Cushing and Harris (1973), showed a mortality of 5% per day (80% per month) for plaice (*Pleuronectes platessa*). Utilizing these estimates, and assuming a hypothetical average larval density of 1 per m³, the number of larvae lost in nature per day throughout New Haven Harbor (volume at mean sea level, 1.2×10^8 m³) would be 6 to 12 million.

TABLE 11-3. IMPACT OF PASSAGE THROUGH THE COOLING WATER SYSTEM FOR FISH SPECIES FROM NEW HAVEN HARBOR, CONNECTICUT. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

SPECIES	LIFE STAGE	AVERAGE DENSITY IN YEAR OF MAXIMUM ABUNDANCE (#/M ³)	SEASON OF OCCURRENCE (MONTHS)	HYDRAULIC DEMAND OF PLANT THROUGH SEASON OF OCCURRENCE (X10 ⁶ M ³)	NUMBER OF INDIVIDUALS PASSING THROUGH PLANT FOR YEAR OF MAXIMUM ABUNDANCE (X10 ⁶)	REMARKS
Winter flounder <i>Pseudopleuronectes americanus</i>	Eggs Larvae	--- .10	--- 4	--- 183	--- 18.0	Non occurring
Windowpane <i>Scopthalmus aquosus</i>	Eggs Larvae	.069 .070	5 2	228 91	16.0 6.4	
Atlantic herring <i>Clupea harengus</i>	Eggs Larvae	--- .014	--- 3	--- 137	--- 1.9	Non occurring
Alewife <i>Alosa pseudoharengus</i>	Eggs Larvae	--- ---	--- ---	--- ---	--- ---	Non occurring None reported
Blueback herring <i>Alosa aestivalis</i>	Eggs Larvae	--- .75	--- 4	--- 183	--- 140.0	Non occurring
American shad <i>Alosa sapidissima</i>	Eggs Larvae	--- .009	--- 1	--- 46	--- 0.41	Non occurring
Menhaden <i>Brevoortia tyrannus</i>	Eggs Larvae	.27 .003	6 5	274 228	74.0 0.68	Equivalent to the egg production of from 112 to 638 females ¹
Scup <i>Stenotomus chrysops</i>	Eggs Larvae	.045 .0006	4 1	183 46	8.2 0.03	
Weakfish <i>Cynoscion regalis</i>	Eggs Larvae	.044 ^a .11	6 2	274 91	12.0 10.0	
Bluefish <i>Pomatomus saltatrix</i>	Eggs Larvae	--- ---	--- ---	--- ---	--- ---	Non occurring Non occurring
Rainbow smelt <i>Osmerus mordax</i>	Eggs Larvae	.010 .0003	4 1	183 46	1.8 0.01	Equivalent to the egg production of 400 females weighing 57 grams ²
Bay anchovy <i>Anchoa mitchilli</i>	Eggs Larvae	36 1.6	4 3	183 137	6600.0 220.0	
Striped bass <i>Morone saxatilis</i>	Eggs Larvae	--- ---	--- ---	--- ---	--- ---	Non occurring Non occurring
Atlantic mackerel <i>Scomber scombrus</i>	Eggs Larvae	4.4 .0007	3 2	137 91	600.0 0.06	Equivalent to the egg production of 1330 medium-sized females ²
Cunner <i>Tautoglabrus adspersus</i>	Eggs Larvae	3.8 ^b .041	5 1	228 46	870.0 1.9	Equivalent to the loss of 44x10 ⁶ larvae ³
Summer flounder <i>Paralichthys dentatus</i>	Eggs Larvae	.001 .006	1 2	46 91	0.05 0.55	

^a may be combined with eggs of *S. chrysops* & *Merluccius* spp. but conservatively assumed to be all *C. regalis*

^b may be combined with eggs of *Limanda ferruginea* but assumed to be all *T. adspersus*

Literature Cited

- ¹ Mansueti, A.J. and J.D. Hardy, 1967.
- ² Bigelow and Schroeder (1953)
- ³ Williams and Williams (1973)

By comparison, assuming the same average larval density of 1 per m³, the maximum daily pumped entrainment impact of New Haven Harbor Station would be 1.5 million larvae.

For relatively stationary resident species, such as the cunner and winter flounder, it is conceivable that an impact of this proportion has ecological significance. How successfully these species have been able to sustain local population numbers, given the additional "predation pressure" represented by New Haven Harbor Station, is assessed by comparing preoperational and operational monitoring data for these species.

None of the species collected in the New Haven Harbor samples depends solely or primarily on the Harbor for successful spawning and rearing of young. This includes all the anadromous species and resident species as well as those that spawn primarily in the open sea (Long Island Sound or beyond). For non-resident species, the pumped entrainment losses cited in Table 11-3 must be considered incidental, however large they may appear to be in absolute terms. Including a few square miles of the Sound in the comparison quickly reduces the proportional impact of New Haven Harbor Station to a negligible value. For example, considering a hypothetical density of 1 larva per m³, the assumed natural loss in Long Island Sound would become approximately 50 million per mi² per day compared to the Harbor Station estimate of 1.5 million/day.

The impact of entrainment on resident species' ecology in New Haven Harbor is moderated by the ability of Long Island Sound to provide recruited larvae and juveniles which replace those destroyed by the generating station. For harbor resident species, egg and larval abundances in Long Island Sound were generally similar to or higher than those in New Haven Harbor, indicating that these species are reproductively independent from New Haven Harbor. Thus, the small proportion of Long Island Sound represented by New Haven Harbor probably limits the overall impact on resident species as well.

Impingement

Aside from other intake features designed to minimize finfish impingement including low intake velocity (see Section 1), to discourage demersal fish from entering the intake structure, a "fish lip" was incorporated into the design. This "lip" rises six feet above the bottom of the intake channel, which in turn extends approximately 900 feet from the eastern edge of the main ship channel to the intake site (Introduction Section 1.0). Diver observations in June 1975 indicated no buildup of sediment on the intake channel bottom prior to the plant beginning operation; thus, it appears that at least in the initial period of operation the lip structure functioned as designed, although its effect on impingement is unknown.

Since New Haven Harbor Station began operation in July 1975, there have been 91 weekly, 24-hr surveys of fish impinged on the traveling screens (Table 11-4). From these data it is possible to estimate the approximate average impingement rate on a daily and annual basis, as shown in Table 11-5. One resident species, winter flounder, and one summer migrant, menhaden, were impinged in relatively large numbers at the New Haven Harbor Station intake. Five other species, windowpane, bay anchovy, blueback herring, weakfish and summer flounder, were impinged in lesser numbers (Table 11-5). Thirty-one additional species were also impinged, but were either uncommon or not included among the representative species chosen for detailed analysis.

It is evident from Table 11-5 that one species, the winter flounder, stands out as having incurred losses large enough to be considered potentially important. Both winters of the plant operation (1975-1976) witnessed equally high numbers of winter flounder impinged (Figure 11-5); it is inferred from this that the fish lip is not effective in eliminating winter flounder impingement. We believe that, although impingement mortality of approximately 27,000 juvenile winter flounder per year is high compared to other Long Island Sound generating stations, this number is not important compared to the natural and fishing mortality of the species. Using published values for survival,

TABLE 11-4. MEAN DAILY IMPINGEMENT OF FINFISH BY MONTH AT NEW HAVEN HARBOR STATION, AUGUST 1975 THROUGH OCTOBER 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	1975												1976												1977											
	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O									
Winter flounder																																				
Menhaden	9.0	5.3	0.7	25.0	0.3	126.0	284.8	498.0	10.0	1.8	3.0	5.3	33.6	9.0		68.0	204.0		302.0	101.5	102.4	3.5	13.6	8.3	23.3	7.7	21.0									
Weakfish																																				
Windownane	7.7	1.0	1.3	0.7	2.8	16.8	3.3	7.0	1.0	1.3	1.0		15.1	2.0					1.0			1.5	4.3	2.4	1.0	1.0	12.0									
Bay anchovy																						0.3	0.5	1.0												
Blueback herring																																				
Summer flounder	20.7																																			
Bluefish	2.7																																			
Atlantic herring																																				
Cunner	0.3	1.0																																		
Mackerel																																				
American shad																																				
Striped bass																																				
Smelt																																				
Scup																																				
Banded killifish	0.3																																			
Black sea-bass																																				
Butterfish	0.7	1.0																																		
Eel																																				
Filefish																																				
Fourspot flounder																																				
Grubby																																				
Halibut																																				
Hogchoker																																				
Little skate																																				
Long-horn sculpin																																				
Moonfish																																				
Mummichog	1.0	0.3																																		
Northern puffer																																				
Northern searobin																																				
Pipefish																																				
Red hake	0.3																																			
Tautog	0.3																																			
Three-spined stickleback																																				
Tomcod																																				
Smooth dogfish	0.3																																			
Striped anchovy	20.0	2.0																																		
Striped searobin	11.7	6.0	8.0	23.3	46.5																															
White perch																																				
Yellowtail	0.7																																			

* Value represents the mean of all the month samples including a value of 1,000 used when numbers of fish were high but were not enumerated.

TABLE 11-5. IMPACT OF IMPINGEMENT ON REPRESENTATIVE IMPORTANT SPECIES.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

<u>SPECIES</u>	AVERAGE NUMBER OF INDIVIDUALS TRAPPED ON NEW HAVEN HARBOR TRAVELING SCREENS (AUGUST 1975 THROUGH OCTOBER 1977)	
	<u>PER DAY</u>	<u>PER YEAR</u>
Winter flounder (<i>P. americanus</i>)	73.1	27,000.0
Windowpane (<i>S. aquosus</i>)	2.8	1,000.0
Atlantic herring (<i>C. harengus</i>)	0.14	51.0
Blueback herring (<i>A. aestivalis</i>)	1.0	365.0
American shad (<i>A. sapidissima</i>)	0.0	0.0
Menhaden (<i>B. tyrannus</i>)	23.9	8,723.5
Scup (<i>S. chrysops</i>)	0.0	0.0
Weakfish (<i>C. regalis</i>)	4.5	1,600.0
Bluefish (<i>P. saltatrix</i>)	0.30	110.0
Smelt (<i>Osmerus mordax</i>)	0.0	0.0
Bay anchovy (<i>A. mitchilli</i>)	3.9	1,400.0
Striped bass (<i>M. saxatilis</i>)	0.0	0.0
Mackerel (<i>S. scombrus</i>)	0.011	4.0
Cunner (<i>T. adspersus</i>)	0.12	44.0
Summer flounder (<i>P. dentatus</i>)	1.0	370.0

age and weight (Hess *et al.*, 1975), 27,000 juvenile winter flounder would survive to approximately 1,755 sexually mature age III fish or about 90 age IV-VI commercial sized fish of about 1 pound. As previously mentioned, the recreational fishery of Long Island alone annually harvests up to 2.5 million winter flounder. The rate of winter flounder impingement appears to be unique to New Haven Harbor Station. Since otter trawl catch-data have given no indication that winter flounder abundances are higher in the area of the intake site than elsewhere in the harbor, it seems likely that the high winter flounder impingement partially reflects the large numbers of small winter flounder normally present in New Haven Harbor.

Menhaden were impinged in relatively large numbers in the spring and fall of 1976 (Figure 11-18), concurrently with observed mass mortalities of this species. We believe that dead and disabled fish accounted for a large proportion of the observed impingement (D. Damer, pers. obs.); no similar impingement occurred in 1975 or 1977.

Thermal Addition

Distribution of heat in New Haven Harbor as affected by New Haven Harbor Station is presented in Section 3.4. The harbor may be characterized in terms of degree of thermal addition in three categories: the discharge plume [elevated 1-8°C (15°F)], the mixing zone (temperature detectably elevated, 0.5-1°C) and the ambient zone (no detectable increase). In the discharge plume, fish are subject to rapid temperature changes that may be of physiologically and behaviorally significant magnitude. If this zone should cover a large or critical portion of the harbor for spawning, feeding, or migration, impacts might result. In the mixing zone, minor impacts might occur when ambient temperatures are near critical values and even slight increases might be important. No impacts would be anticipated in the ambient zone.

The discharge plume area is usually very small in New Haven Harbor, and does not block zones of passage or impinge upon any known critical areas. Since ambient maxima are generally far below critical limits for species present in the harbor, plant-induced increases had no detectable effects.

Ichthyoplankton

In the process of rising to the surface, the thermal discharge stream is partially cooled by mixing with the surrounding colder water. Small, weakly-swimming, or non-swimming life stages may be involuntarily drawn into the effluent stream, along with the plume-entrained parcels of receiving water, and thus be exposed to brief surges of elevated temperature before being cooled to near ambient temperatures as more receiving water is entrained and as the heat is ultimately lost to the atmosphere.

It is important to realize the extreme brevity of this heat exposure; initial temperature surges result in exposure to temperature elevations of up to 8°C above ambient for only a few seconds. At least two recent studies (Hubbs and Bryan, 1974; Schubel, 1974) have shown that fish eggs, a particularly sensitive life stage, are unlikely to be killed outright by this type of exposure (i.e., to heated discharges). Most of the discussion in the more recent scientific literature concerning the impact of thermal discharges has focused on possible sub-lethal effects of the brief exposure (DeSylva, 1969; Kinne, 1970; Miller and Beck, 1975). Due to the subtle nature of these effects, it is impossible to make reasonable, quantitative projections of population losses. As a judgement, it is suggested that the losses presented in Table 11-3 are probably conservative enough to encompass the adverse impact of both passage through the cooling water system and passive entrainment of fish eggs and larvae.

Nekton

Strongly swimming organisms such as juvenile and adult finfish can also be impacted by a thermal plume if they remain in it. The effects of excessive heat exposure may reduce the ability of individuals to avoid further stressful situations. Spigarelli (1975) showed that, although populations of certain species of fish tend to concentrate in a thermal plume, the durations of exposure for individuals were brief. Of the 16 representative species there are nine that have been, or might be, attracted to the New Haven Harbor Station thermal plume. These include: alewife, blueback herring, American shad, menhaden, scup, weakfish, bluefish, bay anchovy and striped bass. In the case of New Haven Harbor Station, the heated water used for condenser cooling is discharged from a diffuser pipe extending several hundred feet from shore into water approximately 35 feet deep. At the calculated discharge velocity, mixing occurs rapidly resulting in a small surface plume that can be occupied by fish. Due to the actions of wind, waves, and tidal currents, the plume is probably somewhat mobile. To remain in the plume, fish must reposition themselves periodically, thereby unavoidably encountering near ambient conditions. Kinne (1970) and others (Wolfson, 1974; Miller and Beck, 1975) have concluded that the intermittent nature of the heat exposure considerably reduces the chances of developing symptoms such as those indicated in Table 11-6. Considering the small size of the plume, its changing shape and distribution, and the motility of these species, it is unlikely that the small percentage of individuals who might develop symptoms of heat exposure will substantially affect the ability of the species in question to sustain present population levels.

Impact

An important consideration in assessing power plant impact is change in species abundance after plant operation begins. Table 11-7 summarizes by month the relative abundance of representative species

TABLE 11-6. SUBLETHAL EFFECTS OF DELIBERATE PROLONGED EXPOSURE TO THERMAL PLUME CONDITIONS. (FROM de SYLVA, 1969 AND KINNE, 1970). NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

1. Increased metabolism (e.g. respiration, heart beat, enzymatic activity, feeding and other body functions)
2. Increased sensitivity to other physiological stress (in winter e.g. cold shock)
3. Neurological responses (dulling of reaction to stimuli, disorientation, etc.)
4. Shortening of duration of early life stages (e.g. early metamorphosis)
5. Out-of-phase reproduction and development
6. Morphometric changes (e.g. smaller body size at comparable growth stage)
7. Decreased growth rate and body mass
8. Inactivation of thermally labile enzymes and processes dependent thereon (e.g. those which control melanism -- the lightening and darkening of body pigments)
9. Increased incidence of disease/parasitism

TABLE 11-7. RELATIVE ABUNDANCE OF REPRESENTATIVE SPECIES COMPARED BY MONTH BETWEEN OPERATIONAL AND PREOPERATIONAL YEARS.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

	J	F	M	A	M	J	J	A	S	O	N	D
Winter flounder	+	+	+	0	-	0	0	+	0	+	0	+
Windowpane	-	-	+	+	0	0	0	+	+	+	+	0
Cunner	+	0	+	0	0	0	0	0	0	0	0	0
Scup	—	—	—	—	0	0	0	0	0	0	—	—
Summer flounder	—	—	—	+	+	0	+	+	+	0	0	—
Atlantic herring	—	—	—	0	+	+	0	—	—	+	+	+
Menhaden	—	—	—	+	+	+	0	0	-	+	—	—
Alewives	—	—	—	0	0	+	+	—	0	0	0	—
Bluebacks	—	—	—	+	0	0	0	0	0	—	—	—
Smelt	0	0	0	0	0	0	0	0	0	0	0	0
Shad	—	—	—	0	+	+	—	—	—	0	0	0
Bay anchovies	—	0	+	+	0	+	0	0	0	0	+	+
Mackerel	—	—	—	0	0	+	—	—	—	—	—	—
Weakfish	—	—	—	0	0	+	0	+	+	—	—	—
Bluefish	—	—	—	0	0	0	-	0	0	—	—	—
Striped bass	—	—	—	0	0	0	0	0	+	0	+	—

— = Not Present

- = Operational below Preoperational Range

+ = Operational above Preoperational Range

0 = Operational within Preoperational Range

between operational and preoperational years. This is based on a comparison of mean abundances for each month of operational (1975-1977) years with the range of monthly mean abundances of preoperational years. If operational mean abundance for a given month is below the preoperational range, a minus (-) appears in the appropriate space on Table 11-7. A minus indicates a lower operational mean than the lowest preoperational mean abundance. This may not indicate an actual decline. Operational mean abundance above the highest preoperational value is indicated by a plus (+) in the appropriate space on Table 11-7. A zero (0) indicates an operational mean within the preoperational range. Most species including cunner, scup, alewives, bluebacks, shad, mackerel, striped bass and smelt show little or no change. Other species such as winter flounder, summer flounder, Atlantic herring, menhaden, bay anchovies and weakfish show an operational abundance greater than preoperational. The only species with a mean operational abundance below the preoperational range for two or more months was the windowpane in January and February. Figure 11-7 presents the means from which Table 11-7 is summarized. Unusually cold winter in the operational years may have caused the slight reduction in abundance observed, or this change may be an artifact of sampling error. There does not appear to be any consistent reduction from preoperational to operational years. We conclude from this result that no impact on the maintenance of a balanced, indigenous assembly of finfish has occurred as a result of New Haven Harbor Station operation.

LITERATURE CITED -- FINFISH

- Atlantic States Marine Fisheries Commission. 1965. Marine resources of the Atlantic coast. Leaflet #2. 80 pp.
- Austin, H. and R. Amish. 1974. Preoperational ecological monitoring program of the marine environs at the LILCO, Shoreham Nuclear Power Station, Shoreham, Long Island, New York. Vol. III: Fishery Ecology. 257 pp.
- Austin, H., M. Dickinson and C. Hickey. 1973. An ecological study of the ichthyofauna at the Northport power station, Long Island New York. Prepared for LILCO by the Fisheries Oceanography Department of the NYOSL. 248 pp.
- Austin, H. M. and O. Custer. 1977. Seasonal migration of striped bass in Long Island Sound. New York Fish and Game Jour. Vol. 24(1):53-68.
- Battelle Columbus Laboratories. 1977. A monitoring program on the ecology of the marine environment of the Millstone Point, Connecticut area. Annual Report Ecological and Hydrographic Studies 1976. Prepared for NUSCO, Berlin, CT. 7 sections.
- Berry, R. J., S. B. Saila and D. B. Horton. 1965. Growth studies of winter flounder, *Pseudopleuronectes americanus* (Walbaum) in Rhode Island. Trans. Am. Fish. Soc. Vol. 94(3):259-264.
- Bigelow, H. B. and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. Fishery Bull. of the Fish and Wildlife Service. Vol. 53. 577 pp.
- Bissel, B. 1971. The fishes of the Mill River. Unpublished course paper: Combined Science 87b, Yale University. C. A. Walker Collection.
- Briggs, P. T. 1965. Sport fisheries for flounder in Long Island Bays. New York Fish and Game Jour. Vol. 12(1):49-72.
- _____. 1975. Shore-zone fishes of the vicinity of Fire Island inlet, Great South Bay, New York. New York Fish and Game Jour. Vol. 22(1):1-12.
- Briggs, P. T. and J. S. O'Connor. 1971. Comparison of shore-zone fishes over naturally vegetated and sand-filled bottoms in Great South Bay. Vol. 18(1):15-41.
- Chao, L. N. and J. A. Musick. 1977. Life history, feeding habits and functional morphology of juvenile sciaenid fishes in the York River Estuary, Virginia. 1977. Fishery Bull. Vol. 75(4):657-702.

- Clark, J. 1968. Seasonal movements of striped bass contingents of Long Island Sound and the New York Bight. Trans. Am. Fish. Soc. Vol. 97(4):320-343.
- Cushing, D. H. and J. G. K. Harris. 1973. Stock and recruitment and the problem of density dependence. Rapp. Proc. Verb. Cons. Perm. Int. Expl. Mer. 164:142155.
- deSylva, D. P. 1969. Theoretical considerations of the effects of heated effluents on marine fishes. IN: Biological Aspects of Thermal Pollution, P. A. Krenkel and F. L. Parker (eds.). Proc. Nat. Symp. Thermal Pollut., Portland, Oregon, June 3-5, 1968. Vanderbilt University Press. pp. 229-243.
- Deuel, D. G., J. R. Clark and A. J. Mansuiti. 1966. Description of embryonic and early larval stages of bluefish, *Pomatomus saltatrix*. Trans. Am. Fish. Soc. Vol. 95(3):264-271.
- Dew, C. B. 1976. A contribution to the life history of the cunner, *Tautogolabrus adspersus*, in Fishers Island Sound, Conn. Ches. Sci. Vol. 17:101-113.
- Equitable Environmental Health, Inc. 1977a. Glenwood Generating Station Final Aquatic Ecology Report. Prepared for LILCO, Hicksville, N. Y. 112 pp.
- _____. 1977b. Northport Generating Station Final Aquatic Ecology Report. Prepared for LILCO, Hicksville, N. Y. 50 pp.
- _____. 1977c. Port Jefferson Generating Station Final Aquatic Ecology Report. Prepared for LILCO, Hicksville, N. Y. 110 pp.
- Federal Water Quality Administration. 1970. New Haven Harbor: Shellfish Resource and Water Quality. U.S. Department of the Interior. 22 pp.
- Finkelstein, S. I. 1971. Migration, rate of exploitation and mortality of scup from the inshore waters of eastern Long Island. New York Fish & Game Jour. Vol. 18(2):95-111.
- Frame, D. W. 1974. Feeding habits of young winter flounder (*Pseudopleuronectes americanus*): prey availability and diversity. Trans. Am. Fish. Soc. Vol. 103 (2):261-269.
- Giron, S. 1972. Commercial fisheries of Long Island Sound. Course paper (Yale University) CSES67b. Long Island Sound Library, Dept. of Geology and Geophysics, Yale Univ., New Haven, CT.
- Green, J. M. and M. Farwell. 1971. Winter habits of the cunner, *Tautogolabrus adspersus* (Walbaum 1792) in Newfoundland. Can. Jour. of Zool. Vol. 49(12):1497-1499.

- Haedrich, R. L. and S. O. Haedrich. 1974. A seasonal survey of the fishes in the Mystic River: a polluted estuary in downtown Boston, Mass. *Estuarine Coastal Marine Science*. Vol. 2:59-73.
- Hess, K. W., M. P. Sissenwine and S. B. Saila. 1975. Simulating the impact of the entrainment of winter flounder larvae. *IN: Fisheries and Energy Production: a symposium* (ed.) S. B. Saila. pp. 1-30.
- Hildebrand, S. F. 1943. Recent review of the American anchovy. *Bull. Bingham Oceanogr. Coll.* Vol. 8, Article 2.
- _____ and W. C. Schroeder. 1928. Fishes of the Chesapeake Bay. *Bull. U.S. Bur. Fisheries*, Vol. 43, part 1. 388 pp.
- Hillman, R., N. Davis and J. Wennemer. 1977. Abundance, diversity and stability in shore-zone fish communities in an area of Long Island Sound affected by the thermal discharge of a nuclear power plant. *Estuar. Coast. Mar. Sci.* 5:355-381.
- Hubbs, C. and C. Bryan. 1974. Effects of parental temperature experience on thermal tolerance of eggs of *Menidia audens*. *Proc. Int. Symp. on the early life history of fish*. Oban. (U.K.), 17 May 1973. J.H.S. Blaxter (ed.), Springer-Verlag, Berlin. pp. 431-435.
- Jensen, A. C. 1970. Thermal loading in the marine district. *New York Fish and Game Jour.* Vol. 17(2):1-80.
- Jones, R. and W. Hall. 1973. A simulation model for studying the population dynamics of some fish species. *IN: The Mathematical Theory of the Dynamics of Biological Populations*.
- Kinne, O. 1970. Temperature. *IN: Marine Ecology*, O. Kinne (ed.). Wiley, New York. Vol. 1(pt. 1):321-616.
- Kissil, G. W. 1974. Spawning of anadromous alewife, *Alosa pseudoharengus* (Wilson) in Bride Lake, Conn. *Amer. Fish. Soc.* 103(2): 312-317.
- Kennedy, V. S. and D. H. Steele. 1971. The winter flounder (*Pseudopleuronectes americanus*) in Long Pond, Conception Bay, Newfoundland. *J. Fish. Res. Bd. Can.* 28:1153-1165.
- Laurence, G. C. 1975. Laboratory growth and metabolism of the winter flounder, *Pseudopleuronectes americanus*, from hatching through metamorphosis at three temperatures. *Mar. Biol.* 32:223-229.
- _____. 1977. A bioenergetic model for the analysis of feeding and survival potential of winter flounder, *Pseudopleuronectes americanus* larvae during the period from hatching to metamorphosis. *Fish. Bull.* Vol. 75(3):529-546.

- Leggett, W. C. 1976. The American shad (*Alosa sapidissima*) with special reference to its migration and population dynamics in the Connecticut River. IN: D. Merriman and L. M. Thorpe (eds.). The Connecticut River Ecological Study. The impact of a nuclear power plant. Am. Fish. Soc. Monogr. No. 1. pp. 169-225.
- Levings, C. D. 1974. Seasonal changes in feeding and particle selection by winter flounder (*Pseudopleuronectes americanus*). Trans. Am. Fish. Soc. 103(4):828-833.
- LILCO. 1977. Port Jefferson Generating Station Final Aquatic Ecology Report. Prepared for LILCO, Hicksville, N. Y. by EEH, Inc. 110 pp.
- Lobell, M. J. 1939. A biological survey of the salt waters of Long Island, 1938. Report on certain fishes, winter flounder (*Pseudopleuronectes americanus*). Suppl. 28th Ann. Rep. N.Y. Cons. Dept., Pt. 1. 63-96.
- Lund, W. A., Jr. and G. C. Maltezos. 1970. Movements and migrations of the bluefish, *Pomatomus saltatrix*, tagged in waters of New York and southern New England. Trans. Am. Fish. Soc. 4:719-725.
- Lux, F. E. 1973. White spotting in the 1959 year class of Georges Bank winter flounder, *Pseudopleuronectes americanus* (Walbaum). Trans. Am. Fish. Soc. (1):83-88.
- _____. 1973b. Age and growth of the winter flounder, *Pseudopleuronectes americanus*, on Georges Bank. Fishery Bull. Vol. 71(2):505-512.
- Mansueti, A. J. and J. D. Hardy. 1967. Development of fishes of the Chesapeake Bay Region. Part 1. Port City Press, Baltimore, MD. 202 pp.
- Marcy, B. C. 1975. Entrainment of organisms at power plants, with emphasis on fishes -- an overview. IN: Fisheries and Energy Production: a symposium (ed. S. B. Saila). 89-106 pp.
- _____. 1976. Early life history studies of American shad in the lower Connecticut River and the effects of the Connecticut Yankee Plant. IN: D. Merriman and L. M. Thorpe (eds.). The Connecticut River Ecological Study. The impact of a nuclear power plant. Am. Fish. Soc., Monogr. No. 1. pp. 141-168.
- _____. 1969. Age determinations from scales of *Alosa pseudoharengus* (Wilson) and *Alosa aestivalis* (Mitchell) in Connecticut waters. Trans. Am. Fish. Soc. Vol. 98(4):622-630.
- McCracken, S. D. 1963. Seasonal movements of the winter flounder, *Pseudopleuronectes americanus* (Walbaum) on the Atlantic coast. Jour. Fish. Res. Bd. Can. Vol. 20(2):552-585.

- Merriman, D. 1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic coast. U.S. Fish and Wildl. Serv. Fish. Bull. 50(35): 1-77.
- Merriman, D. and R. C. Sclar. 1952. The pelagic fish eggs and larvae of Block Island Sound. Bull. of Bingham Ocean. Coll. XIII:3:165-216.
- Miller, D. C. and A. D. Beck. 1975. Development and application of criteria for marine cooling waters. IN: Environmental effects of cooling systems at nuclear power plants. Proc. Int'l. Atomic Energy Agency, Vienna, Austria. p. 639-657.
- Moore, E. 1947. Studies on the marine resources of southern New England. The Sand Flounder. Bull of the Bingham Ocean. Col. Vol. XI(3): 1-79.
- Nelson, W. R., M. C. Ingham and W. E. Schaaf. 1977. Larval transport and year class strength of Atlantic menhaden, *Brevoortia tyrannus*. Fishery Bull. 75(1):23-42.
- New York Ocean Science Laboratory. 1974a. Preoperational Ecological Monitoring program at the marine environs at LILCO, Shoreham Nuclear Power Station, Shoreham, New York. Volume 3:Fishery Ecology.
- _____. 1974b. Preoperational ecological monitoring program of the marine environs at the LILCO nuclear power station, Shoreham, New York. Vol. 11:Phytoplankton, Zooplankton and Ichthyoplankton. 3 sections.
- Nichols, J. T. and C. M. Breder, Jr. 1926. The marine fishes of New York and southern New England. Zoologica Vol. IX, No. 1. pp. 1-192.
- Norcross, J. J., S. L. Richardson, W. H. Massman and E. B. Joseph. 1974. Development of young bluefish (*Pomatomus saltatrix*) and distribution of eggs and young in Virginian coastal waters. Trans. Am. Fish. Soc. 103(3):477-497.
- Normandeau Associates, Inc. 1973a. New Haven Harbor Ecological Studies, New Haven, Connecticut. Annual Report, 1971-1972 for The United Illuminating Company, New Haven, Connecticut. 208 pp.
- _____. 1973b. Bridgeport Harbor Ecological Studies, 1971-1972. Biological and Hydrographic Reports. Prepared for The United Illuminating Company, New Haven, Connecticut. 196 pp.
- _____. 1974a. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report, 1972-1973 for The United Illuminating Company, New Haven, Connecticut. 215 pp.

- _____. 1974b. Coke Works Ecological Monitoring Studies, New Haven Harbor, Connecticut. Interim Report, May-December 1973 for The United Illuminating Company, New Haven, Connecticut. 199 pp.
- _____. 1974c. Stamford Harbor Ecological Studies, Stamford, Connecticut. Prepared for NUSCO, final report 1971-1973. 159 pp.
- _____. 1974d. Supplemental research on the effects of thermal discharge from the English Generating Station on the ecology of Grand Avenue Reach, New Haven Harbor, Connecticut. Prepared for The United Illuminating Company, New Haven, Connecticut. 120 pp.
- _____. 1975a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1974 for The United Illuminating Company, New Haven, Connecticut. 223 pp.
- _____. 1975b. Ecological studies conducted at selected sites in New Haven Harbor, Connecticut. Prepared for the City of New Haven, Connecticut. 115 pp.
- _____. 1976a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1975 for The United Illuminating Company, New Haven, Connecticut. 312 pp.
- _____. 1977a. New Haven Harbor Station Ecological Monitoring Studies, New Haven Harbor, Connecticut. Annual Report 1976 for The United Illuminating Company, New Haven, Connecticut. 376 pp.
- _____. 1978. New Haven Harbor Station Ecological Monitoring Study, New Haven Harbor, Connecticut. Annual Report 1977 for The United Illuminating Company, New Haven, Connecticut. 359 pp.
- NUSCO. 1976. Data report of fin and shell fish impinged from August 1975 to August 1976 at Devon Station, Middletown Station, Norwalk Harbor and Montville Station. 37 pp.
- _____. 1977. Annual report Millstone Nuclear Power Station Entrainment Studies Units 1 and 2.
- Olla, B. L., A. J. Bejda and A. D. Martin. 1974. Daily activity, movements, feeding and seasonal occurrences in the tautog, *Tautoga onitis*. Fishery Bull. Vol. 72(1):27-36.
- _____. 1975. Activity, movements and feeding behavior of the cunner, *Tautoglabrus adspersus*, and comparison of food habits with young tautog, *Tautoga onitis*, off Long Island, New York. Fishery Bull. Vol. 73(4):895-900.
- Oviatt, C. A., A. L. Gall and S. W. Nixon. 1973. Environmental effects of Atlantic menhaden on surrounding waters. U.R.I. School of Oceanography, Sea Grant Contract. 165-009.

- Pearcy, W. G. 1962. Ecology of an estuarine population of winter flounder (*Pseudopleuronectes americanus*). Bull. of Bingham Ocean. Coll. XVIII:5-77.
- _____ and S. W. Richards. 1962. Distribution and ecology of fishes of the Mystic River Estuary, Conn. Ecology. Vol. 43(2):248-259.
- Perlmutter, A. E. 1947. The blackback flounder and its fishery in New England and New York. Bull. Bingham Ocean. Col. 11(2):1-92.
- _____. 1969. Ecological study 1968 of the aquatic environs of the proposed Shoreham Nuclear Power Station. Prepared for LILCO.
- _____. 1970. Ecological study 1969. Shoreham Nuclear Power Station. Prepared for LILCO.
- Perlmutter, A. E. 1970. Ecological Study of Shoreham Nuclear Power Station. Prepared for LILCO.
- Perlmutter, A., W. S. Miller and J. C. Poole. 1956. The weakfish (*Cynoscion regalis*) in New York waters. New York Fish and Game Jour. Vol. 3(1):1-43.
- Pierce, D. E. and A. B. Howe. 1977. A further study on winter flounder group identification off Massachusetts. Trans. Am. Fish. Soc. Vol. 106(2):131-139.
- Poole, J. C. 1961. Age and growth of the fluke in Great South Bay and their significance to the sport fishery. New York Fish & Game Jour. Vol. 8(1):1-18.
- _____. 1962. Growth and age of winter flounder in four bays of Long Island. New York Fish and Game Jour. Vol. 13(2):207-220.
- Raytheon Company. 1971. New Haven Harbor Ecological Survey, Data Report, December 1970-April 1971. Prepared for The United Illuminating Company, New Haven, Connecticut.
- Reisman, H. H. and W. Nicol. 1973. The fishes of Gardiner's Island, New York. Vol. 30(1):25-31.
- Richards, S. W. 1959. Pelagic fish eggs and larvae of Long Island Sound. Bull. of Bingham Coll. XVII:95-123.
- _____. 1963. The demersal fish populations of Long Island Sound. Bull. of Bingham Ocean Coll. XVIII:5-101.
- Ricker, W. E. 1975. Computations and interpretation of biological statistics of fish populations. Canada Department of the Environment Fisheries and Marine Service. 382 pp.

- Schaefer, R. H. 1967. Species composition, size and seasonal abundance of fish in the surf waters of Long Island. New York Fish. & Game Jour. Vol. 14(1):1-46.
- Schubel, J. R. 1974. Effects of exposure to time-excess temperature histories typically experienced at power plants on the hatching success of fish eggs. Estuar. Coast. Mar. Sci. 2:105-116.
- Spigarelli, S. A. 1975. Behavioral responses of Lake Michigan fishes to a nuclear power plant discharge. IN: Environmental effects of Cooling Systems at Nuclear Power Plants. Proc. Intl. Atomic Energy Agency, Vienna, Austria. pp. 479-498.
- Stickney, R. R., G. L. Taylor and D. B. White. 1975. Food habits of five species of young southeastern United States estuarine sciaenidae. Chesapeake Sci. Vol. 16(2):104-114.
- Stone and Webster. 1977. Supplemental assessment in support of the 316 demonstration. Pilgrim Nuclear Power Station Units 1 and 2. 12 sections.
- Stupka, R. C. and K. Sharma. 1977. Survey of fish impingement at power plants in the United States. Vol. III: Estuarine and Coastal waters. Argonne National Laboratory. Report. No. ANL/ES-56. 310 pp.
- Thomson, K. S., W. H. Weed and A. G. Tarushi. 1971. The marine fishes of Connecticut. State GEol. and Natu. Hist. Sur. Conn. Bull.
- United Illuminating Company. 1977. New Haven Harbor Station #1 impingement data. mimeo, raw data.
- Warfel, H. E. and D. Merriman. 1944. Studies on the marine resources of southern New England. I. An analysis of the fish population of the shore zone. Bull. Bingham Oceanogr. Coll. 9(2).
- Wells, B., D. H. Steele and A. V. Tyler. 1973. Intertidal feeding of winter flounder (*Pseudopleuronectes americanus*) in the Bay of Fundy. J. Fish. Res. Bd. Can. 30:1374-1378.
- Westman, J. R. and R. F. Nigrelli. 1955. Preliminary studies of menhaden and their mass mortalities in Long Island and New Jersey waters. New York Fish and Game Jour. Vol. 2(2):143-153.
- Wheatland, S. B. 1956. Oceanography of Long Island Sound, 1952-1954. VII: Pelagic fish eggs and larvae of Long Island Sound. Bull. Bingham Oceanogr. Coll. 15:234-313.
- Williams, G. C., D. G. Williams and R. J. Miller. 1973. Mortality rates of planktonic eggs of the cunner, *Tautoglabrus adspersus* (Walbaum) in Long Island Sound. IN: Proceedings of a Workshop on Egg, Larval and Juvenile Stages of Fish in Atlantic Coast Estuaries (June 1968). USDC, NOAA, NMFS Middle Atlantic Coastal Fisheries Center, Tech. Publ. No. 1. 338 pp.

Wolfson, A. A. 1974. Some effects of increased temperature on the settlements and development of a marine community in the laboratory. Univ. Calif. San Diego. Sea Grant Publ. 39.

Young, J. S. 1974. Menhaden and power plants -- a growing concern. Marine Fisheries Review. Vol. 36(10):19-23.

_____ and C. I. Gibson. 1973. Effect of thermal effluent on migrating menhaden. Marine Pollut. Bull. Vol. 4(6):94-96.

Zawacki, C. S. and P. T. Briggs. 1976. Fish investigations in Long Island Sound at a nuclear power station at Shoreham, New York. N.Y. Fish and Game Jour. Vol. 23(1):34-50.

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

12.0 MIGRATORY WATERFOWL, GULL AND SHOREBIRD SURVEY

by Michael M. Grubb and Ken Norcross

Normandeau Associates, Inc.
Bedford, N. H.

TABLE OF CONTENTS

	PAGE
INTRODUCTION.	12-1
STUDY METHODS	12-1
CHARACTERIZATION OF NEW HAVEN HARBOR AVIFAUNA	12-5
Species Diversity (as total number of species).	12-5
Abundance	12-13
Waterfowl	12-16
Gulls	12-18
Shorebirds.	12-19
Distribution Within the Harbor.	12-20
Observations of Rare or Uncommon Species.	12-26
ANALYSIS OF IMPACTS OF NHHS OPERATION ON AVIFAUNA	12-28
Abundance	12-29
Waterfowl	12-29
Gulls	12-33
Shorebirds.	12-33
Impacts on Avian Food Sources	12-35
Fish.	12-35
Intertidal Benthos.	12-37
Subtidal Benthos.	12-38
SUMMARY	12-38
LITERATURE CITED.	12-40
APPENDICES.	12-43

LIST OF FIGURES

	PAGE
12-1. Designated study areas for avian census conducted in New Haven Harbor, Connecticut.	12-4
12-2. Number of species of waterfowl, gulls and shorebirds observed, 1972-1977.	12-6
12-3. Average number of waterfowl species and individuals observed in New Haven Harbor, 1972-1976	12-10
12-4. Average number of shorebird species and individuals observed in New Haven Harbor 1972-1976.	12-11
12-5. Average number of gull species and individuals observed in New Haven Harbor 1972-1976.	12-12
12-6. Seasonal abundance of birds at New Haven Harbor, based on 1972-1976 average of fifteen representative species listed in Appendix Table 2	12-14
12-7. Average number of waterfowl, gulls and shorebirds observed at various areas of New Haven Harbor from 1972-1976 surveys.	12-21
12-8. Numbers of waterfowl, gulls and shorebirds observed at various areas of New Haven Harbor, 1972-1976. Dashed lines represent five year means. . .	12-22
12-9. Total number of birds observed in New Haven Harbor for each year, 1972-1977.	12-30
12-10. Total number of birds observed in January, July and October for each of the years 1972-1977	12-31
12-11. Total number of waterfowl, gulls and shorebirds observed in New Haven Harbor for the years 1972-1977.	12-32
12-12. Comparison of numbers of scaup observed in Long Island Sound and in New Haven Harbor, 1972-1976	12-34
12-13. Preoperational and operational comparisons of percent of total catch and frequency of capture	12-36

LIST OF TABLES

		PAGE
12-1.	FIFTEEN AVIAN SPECIES SELECTED FOR ANALYSIS.	12-3
12-2.	TOTAL NUMBER OF SPECIES AND BIRDS OBSERVED 1972-1977.	12-7
12-3.	AVERAGE SPECIES DIVERSITY (TOTAL NUMBER OF SPECIES) AND ABUNDANCES (MONTHLY AVERAGES) OF ALL BIRDS OBSERVED AT NEW HAVEN HARBOR, 1972-1976.	12-9
12-4.	RARE OR UNUSUAL SPECIES OBSERVED IN NEW HAVEN HARBOR, 1971-1977.	12-27

12.0 MIGRATORY WATERFOWL, GULL AND SHOREBIRD SURVEY

by Michael H. Grubb and Ken Norcross
Normandeau Associates, Inc.
Bedford, N. H.

INTRODUCTION

New Haven Harbor, though not utilized as a nesting area, is an important feeding and resting area for shorebirds, gulls and waterfowl. It also provides habitat for cormorants, herons, loons, grebes and other waterbirds. A censusing program was initiated in June 1971 to monitor avian abundance, species composition and seasonal and spatial distribution. This program was designed to determine any major changes in avian utilization of New Haven Harbor as a result of operation of the New Haven Harbor Station.

STUDY METHODS

Data used in the preparation of this section of the report were collected under the supervision of NAI for studies funded by United Illuminating Company. Data collection began in June 1971 and terminated in October 1977. Surveys were conducted at least once a month in addition to additional surveys during late fall and winter months to provide a more accurate estimate of peak migratory populations. Data from multi-sampled months were averaged to yield one figure for each month.

During each survey, observations were made from a series of approximately 12 stations beginning south of Sandy Point and progressing clockwise around the harbor. Surveys were conducted from shore with the aid of binoculars and a 20-45X spotting scope. Personnel recorded the number and species of all birds near enough to be identified. From June 1971 through August 1972, and July 1976 through October 1977, data sheets were used with a section for comments on bird activity, human disturbance, unusual conditions or any other factors that might influence the data. From September 1972 through June 1976 only raw numerical data were recorded.

Data were tabulated and compared by calendar year. Because only 6 months of data were collected in 1971 and only 10 months in 1977, data for those years were not directly utilized in multi-annual data compilations.

Fifteen of the most abundant and representative species were selected for in-depth analysis (Table 12-1). These were the consistently more abundant species from each of the three groups under consideration (waterfowl, shorebirds and gulls) as well as two additional species, the horned grebe (*Podiceps auritus*) and common tern (*Sterna hirundo*). The data from these species have been used in the discussion of trends and relative abundance.

For purposes of collecting and interpreting the data, the harbor was divided into five areas (Figure 12-1) designated as follows:

1. East Shore: Coast Guard station to Lighthouse Point and extending out into the shipping channel.
2. Harbor Station Area: Tomlinson Bridge to the Coast Guard Station and extending into the harbor to the shipping channel and the West River channel.
3. Long Wharf Area: From Tomlinson Bridge to City Point and extending into the harbor to the shipping channel and the West River channel. (This area adjoins both proposed sewage treatment plant sites).
4. West River Area: From a line from City Point to the tip of Sandy Point up the West River to the I-95 bridge (beyond Kimberly Harbor).
5. Sandy Point and West Shore Area: Sandy Point and adjoining waters to the West River channel and the main shipping channel, extending one-half mile along the shore to the southwest of Sandy Point.

TABLE 12-1. FIFTEEN AVIAN SPECIES SELECTED FOR ANALYSIS. NEW HAVEN
HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

Horned grebe
Black duck
Canvasback
Scaup spp.
Common goldeneye
Bufflehead
Black-bellied plover
Dunlin
Sanderling
Semipalmated sandpiper
Great black-backed gull
Herring gull
Ring-billed gull
Bonaparte's gull
Common tern



Figure 12-1. Designated study areas for avian census conducted in New Haven Harbor, Connecticut. New Haven Harbor Ecological Studies Summary Report, 1979.

For the discussion of geographic importance of each area, the avian population was divided into waterfowl (ducks, geese and swans), shorebirds (sandpipers and plovers) and gulls. All species identified within these groups (in addition to those listed in Table 12-1) were included in the calculations for Figures 12-2 through 12-5 and 12-7 through 12-11. Because the focus of this study was on the aquatic environment of New Haven Harbor, all species that were not considered to be water birds (and usually sighted in the upland areas bordering the shore) were grouped under a miscellaneous category. Data on these species (primarily passerines) are not included in any of the following discussion.

CHARACTERIZATION OF NEW HAVEN HARBOR AVIFAUNA

Species Diversity (as total number of species)

A total of 125 species were observed in New Haven Harbor during the period 1971-1977 (Appendix Table 12-1). The family Scolopacidae (shorebirds) had the highest representation with 21 species present. Total number of species observed annually was fairly constant (38 to 41) during the four-year period of 1972-1975 (Table 12-2). The large increase from approximately 35 species per year to 92 species in 1976 and 91 during the ten months of 1977 was due primarily to limited sightings of each of many species of land birds, termed "miscellaneous " in this study. During the 1972-1975 period, less than 10 miscellaneous species were observed while 29 species were observed in 1976 and 35 in 1977. Numbers of shorebird species observed also increased in 1976 and 1977 (Figure 12-2). These increases are attributed to the changing of personnel conducting the study. Although methods of observations were standardized from year to year, the ability to distinguish some of the more uncommon species and attention to detail did vary between observers. Because the more recent observers focused on land species previously ignored and because only a few individuals of the newly sighted species were observed, this change in species diversity is unimportant and probably, in fact, does not represent a change at all.

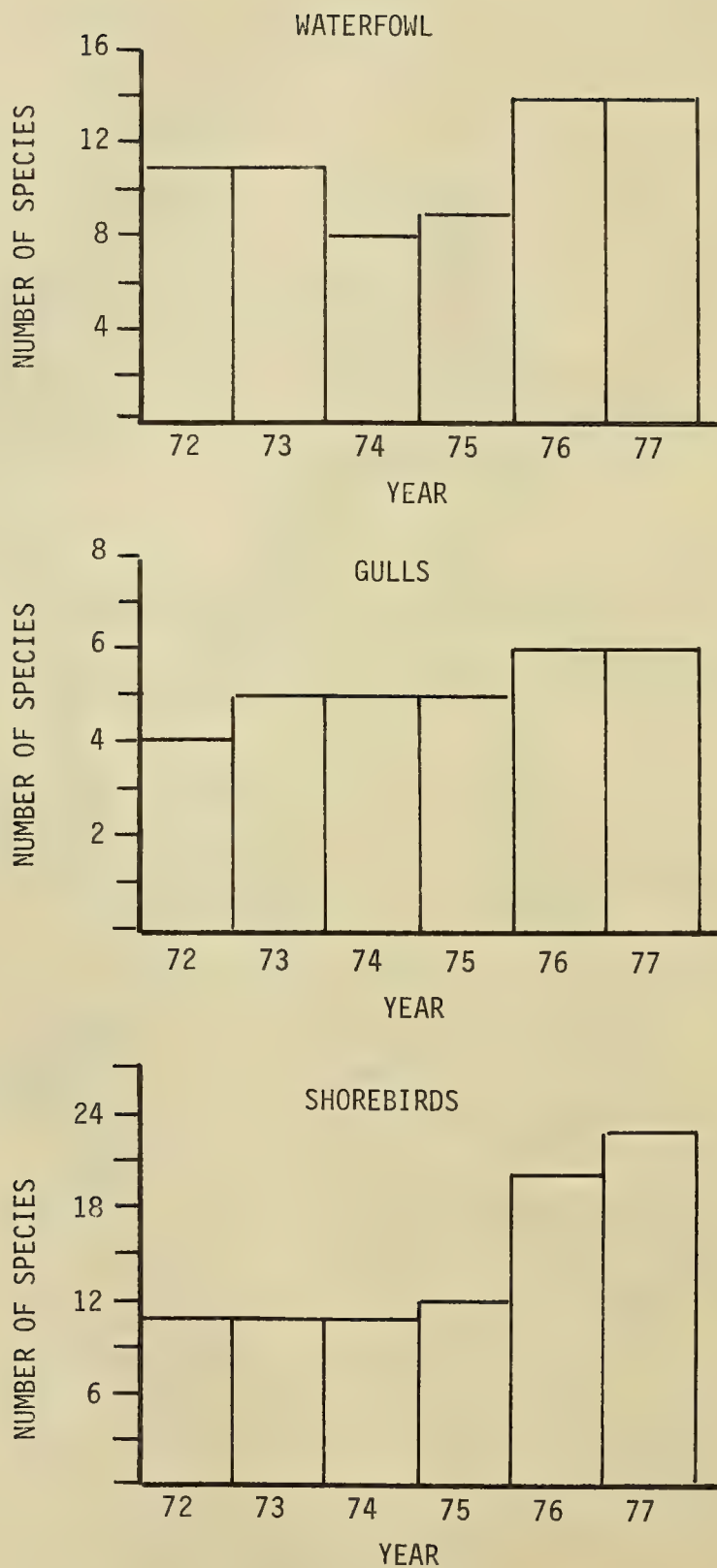


Figure 12-2. Number of species of waterfowl, gulls and shorebirds observed, 1972-1977. New Haven Harbor Ecological Studies Summary Report, 1979.

TABLE 12-2. TOTAL NUMBER OF SPECIES AND BIRDS OBSERVED 1972-1977.
NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

YEAR	TOTAL NUMBER OF SPECIES	TOTAL NUMBER OF BIRDS
1972	38	39,611
1973	41	32,050
1974	38	26,883
1975	40	40,258
1976	92	34,888
1977*	91	25,910

$$\bar{x} = 34,738$$

* 10 months only

Monthly species diversity was variable (Table 12-3). Generally, fewest species were observed in spring and highest numbers observed in summer and fall. The lowest number of species recorded was 4 in June 1977 and the highest was 54 in August 1977. The highest number of waterfowl species was observed during the winter months while greatest number of shorebird species occurred during spring and summer; species diversity of gulls did not vary seasonally (Figure 12-3, 12-4 and 12-5).

The seasonal distribution of species was typical of coastal areas in the latitude of New Haven. The number of waterfowl species increased during fall, remained high during winter, then decreased to low numbers in summer (Figure 12-3). The increase resulted from the influx of birds from Canada and northern New England which utilize New Haven Harbor either as a resting habitat before migrating further south, or as a wintering habitat. The spring decrease in waterfowl species occurred as the birds departed for their traditional breeding grounds in Canada and the northern United States (Kortright, 1942).

In exact opposition to this pattern was that exhibited by shorebirds. The number of species of these birds was highest in the summer (Figure 12-4). Shorebirds breed in the vicinity of New Haven as well as areas farther north and, in addition, those yearling shorebirds that do not breed remain on their wintering ground or along the migration routes which include coastal New England. During the winter months shorebirds inhabit the southern United States, the Caribbean and South America (Stout, 1967).

The June observations of extremely low numbers of shorebirds (Figure 12-4) does not correspond with what would be expected at this time of year. Examination of the raw data revealed that of the five census periods conducted during June (one each year from 1972 - 1976), four were conducted at high tide. Shorebirds that feed on intertidal flats or in shallow water would be expected to utilize the areas in New Haven Harbor at low tide and to be found elsewhere at high tide. In a similar situation, Burger *et al.*, 1977 found shorebirds feeding on New Jersey tidal flats to be a function of tide time rather than time of

TABLE 12-3. AVERAGE SPECIES DIVERSITY (TOTAL NUMBER OF SPECIES) AND ABUNDANCES (MONTHLY AVERAGES) OF ALL BIRDS OBSERVED AT NEW HAVEN HARBOR, 1972-1976. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

MONTH	TOTAL NUMBER OF SPECIES		ABUNDANCE	
	AVERAGE	RANGE	AVERAGE	RANGE
January	15	10-18	3,117	1,229- 4,984
February	15	13-17	6,817	2,817-11,704
March	14	12-16	5,656	862-11,982
April	13	10-17	1,427	579- 2,189
May	17	10-30	1,324	638- 1,986
June	10	4-15	1,046	151- 2,586
July	20	13-40	2,536	804- 7,163
August	20	11-39	1,927	1,096- 3,547
September	19	11-37	1,725	368- 2,776
October	24	13-46	1,518	769- 2,342
November	20	13-35	3,800	2,606- 5,628
December	16	10-27	2,939	1,631- 5,007

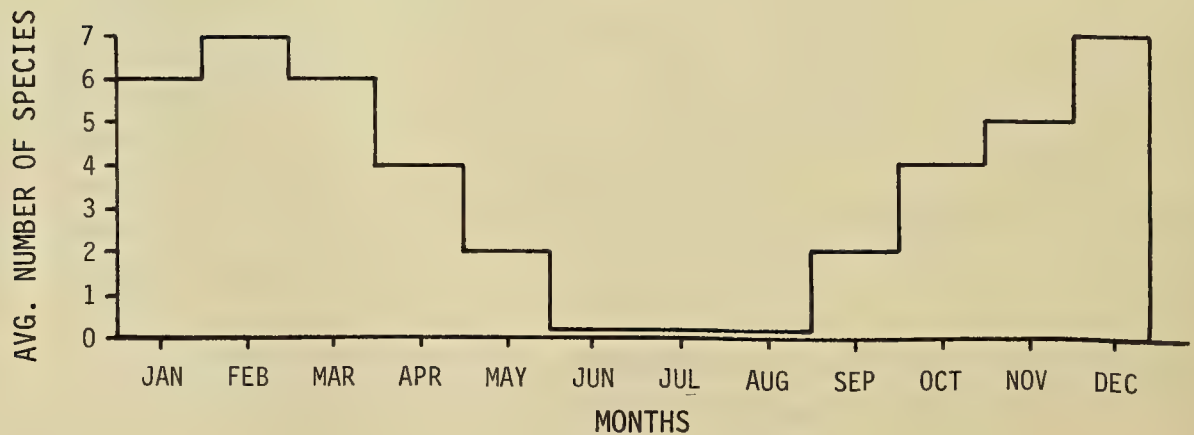
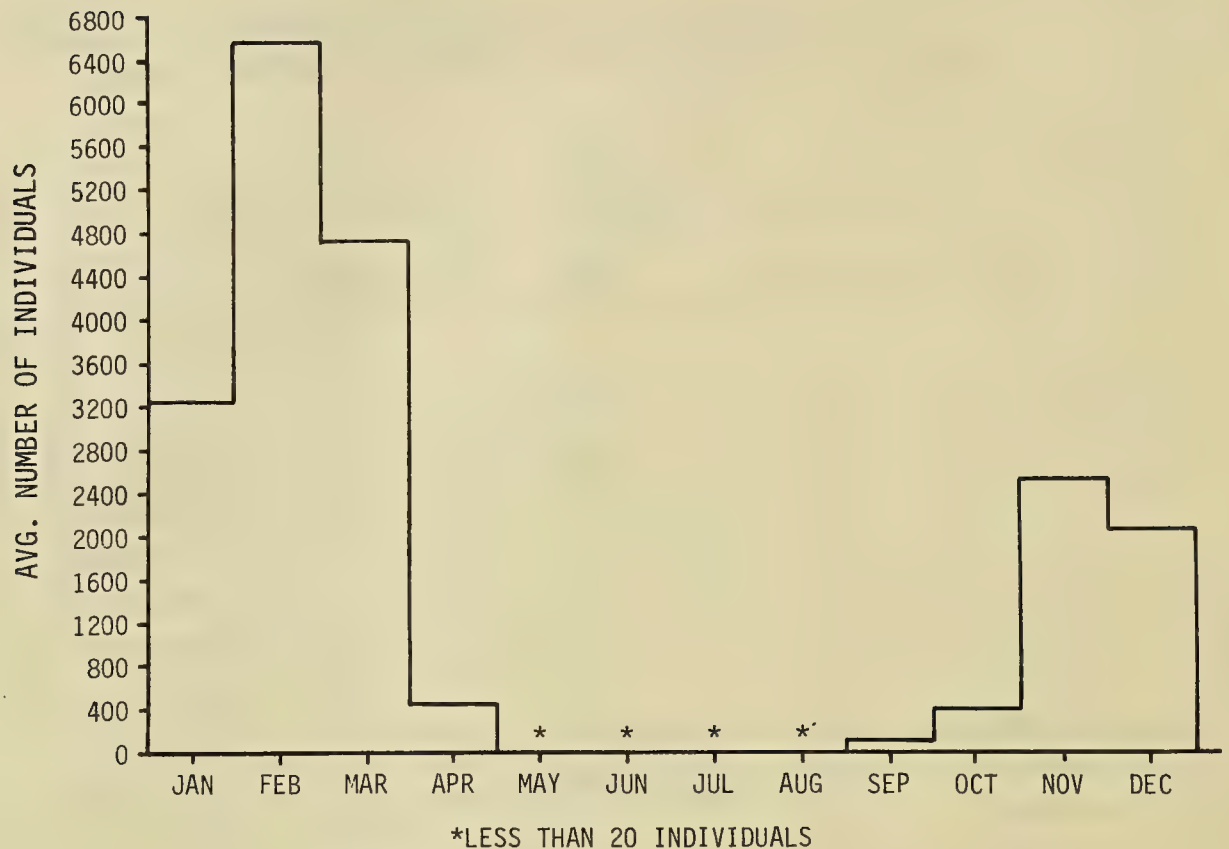


Figure 12-3. Average number of waterfowl species and individuals observed in New Haven Harbor, 1972-1976. New Haven Harbor Ecological Studies Summary Report, 1979.

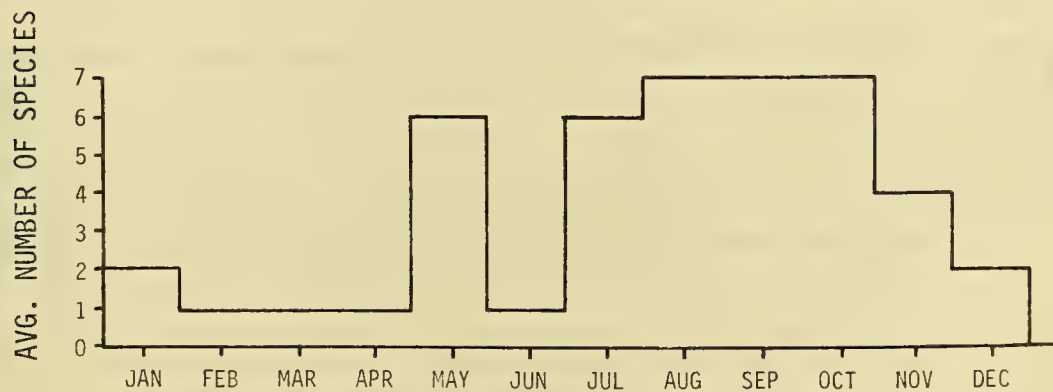
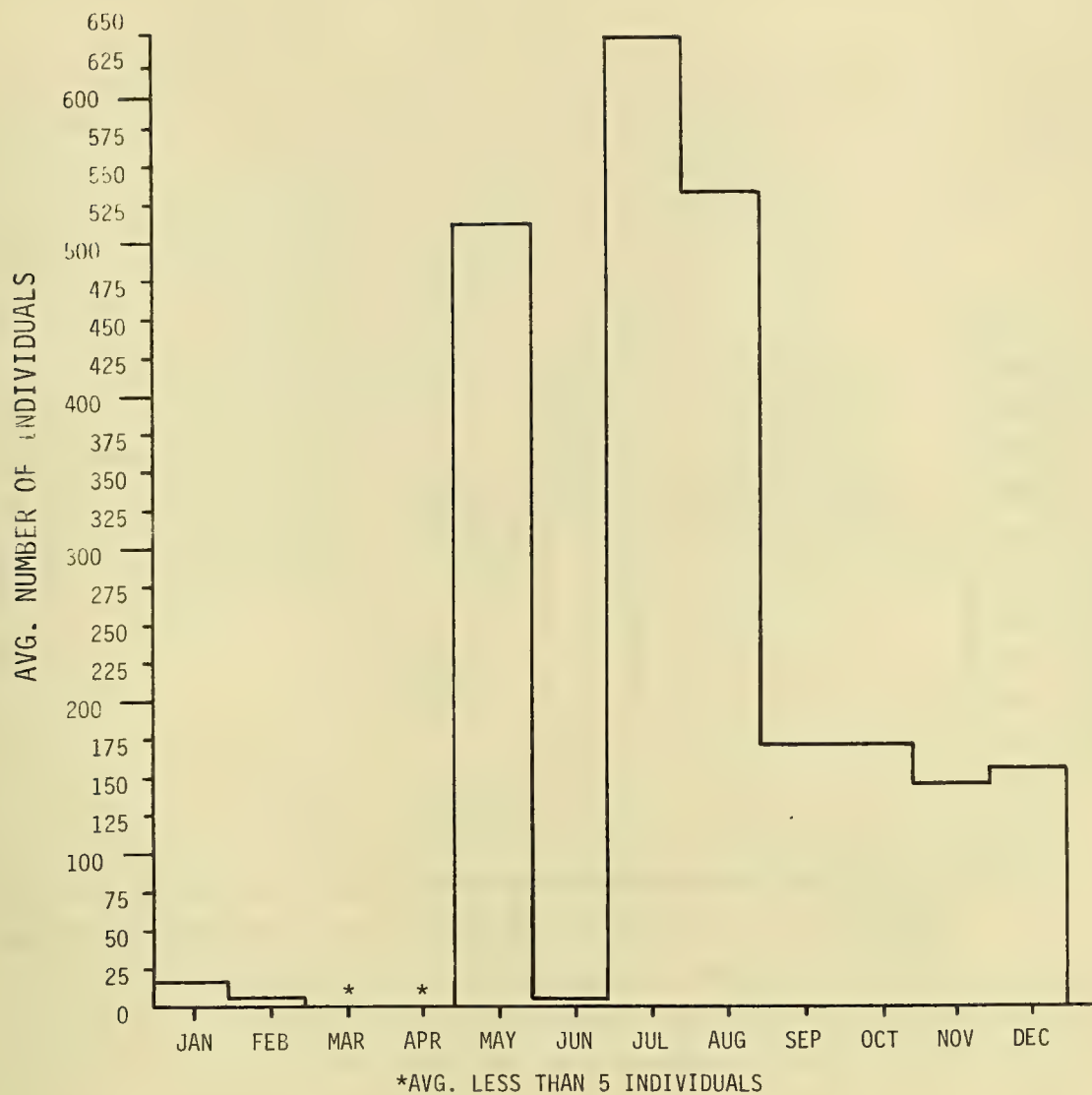


Figure 12-4. Average number of shorebird species and individuals observed in New Haven Harbor 1972-1976. New Haven Harbor Ecological Studies Summary Report, 1979.

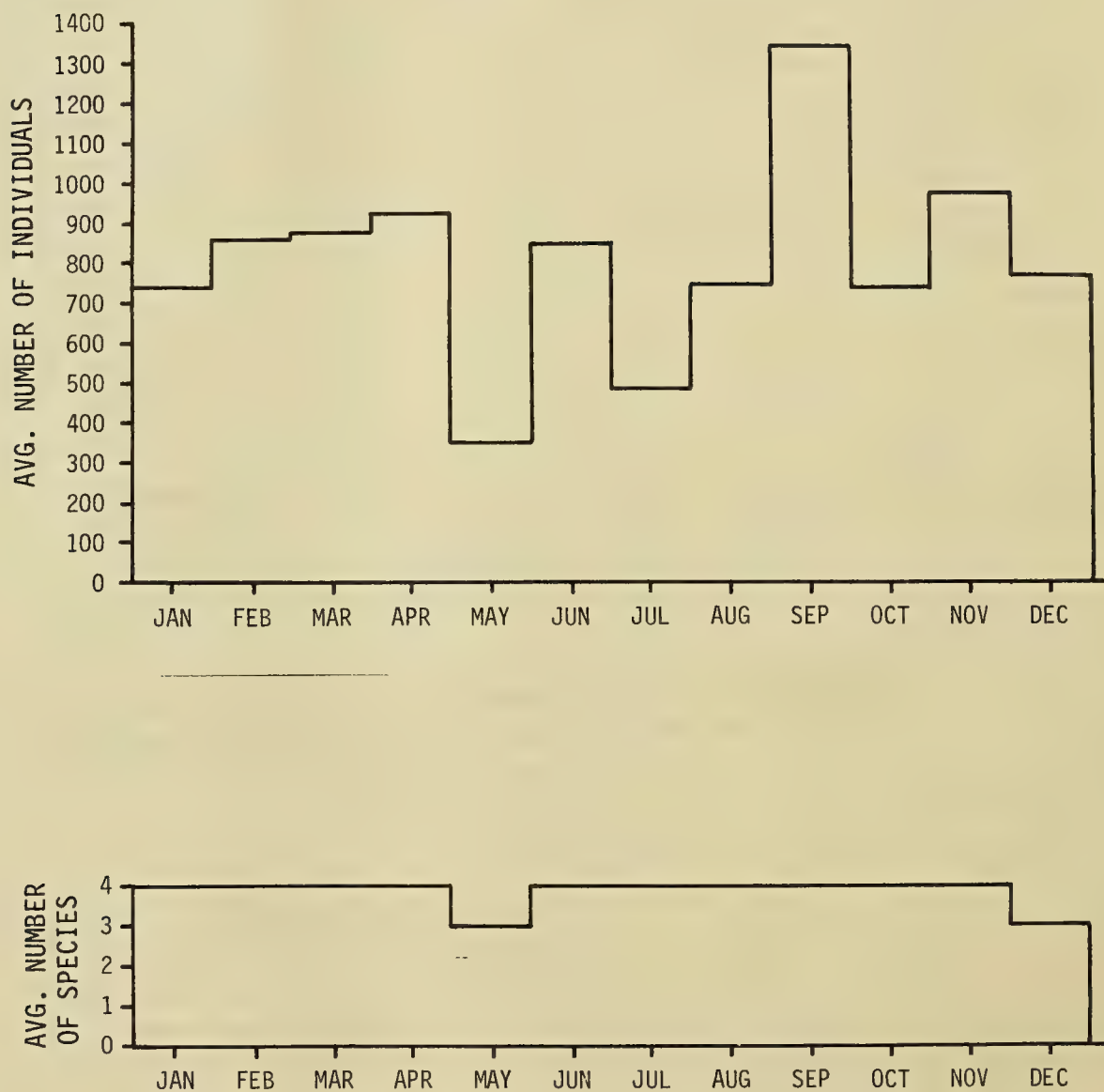


Figure 12-5. Average number of gull species and individuals observed in New Haven Harbor 1972-1976. New Haven Harbor Ecological Studies Summary Report, 1979.

day; highest concentrations of birds occurred shortly after low tide on mudflats and outer beach habitats and after high tide on inner beach habitats. Thus, the disproportionate amount of June censusing at high tide in New Haven probably explains the low recordings of shorebird number and species during this month.

Gull species diversity remained constant throughout the year (Figure 12-5). Although gulls are considered migratory species, there is considerable overlap in ranges of different populations. In addition, some migrations may be very short, resulting in no noticeable influx or outflow from an area in either species diversity or numerical abundance.

Abundance

The total number of birds observed ranged from just under 27,000 in 1974 to over 40,000 in 1975 (Appendix Table 12-2). Such year-to-year fluctuation in numbers is expected due to factors related to sampling, such as weather, tide level at time of sampling, coincidence of observations with timing of population movements, and variations inherent in visual population estimation, as well as short- and long-term fluctuations in abundances of individual species populations.

In each study year, bird counts began increasing in November, and remained at high levels, peaking in February (Figure 12-6). Numbers then dropped off with lowest numbers of birds observed in the period of May through July. Waterfowl numbers were highest in the winter months while shorebird numbers peaked in the summer. Gulls were present in large numbers all year and showed no pattern of fluctuation (Figure 12-3, 12-4 and 12-5).

The overall seasonal abundance of birds is due to the same factors that explain seasonal differences in species diversity, i.e. timing of migrations by the various groups. This trend in both seasonal species diversity and seasonal fluctuations in overall numbers was present in all five years of study.

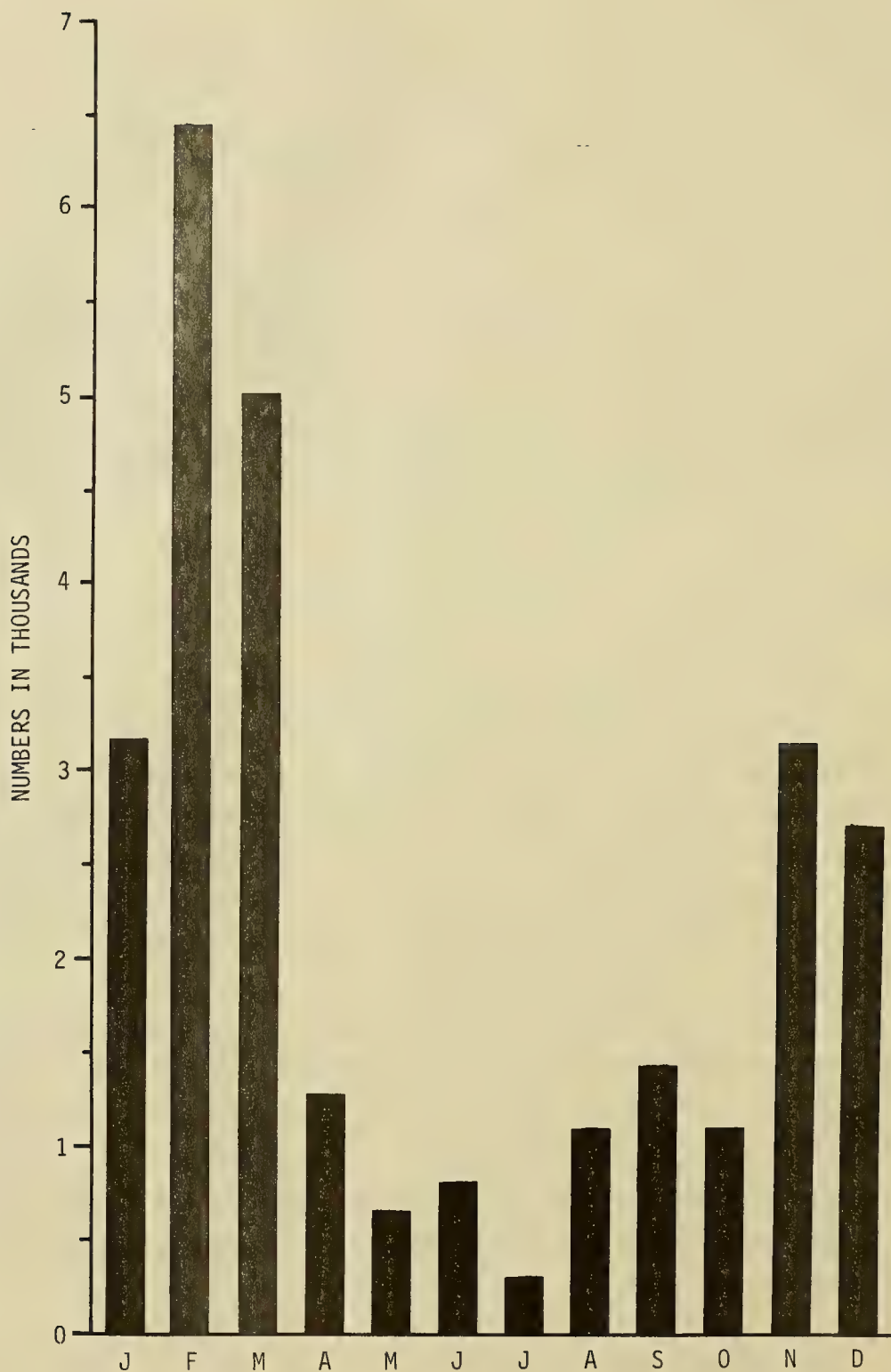


Figure 12-6. Seasonal abundance of birds at New Haven Harbor, based on 1972-1976 average of fifteen representative species listed in Appendix Table 2. New Haven Harbor Ecological Studies Summary Report, 1979.

Scaup (*Aythya* spp.) were by far the most abundant species sighted. For the five year study period these birds averaged 35% of all sightings. For the month of March they averaged 80% of all birds observed. Total yearly scaup sightings ranged from 6400 to 19,600 (Appendix Table 12-2). The black duck (*Anas rubripes*) was the second most abundant species, averaging 14% of all sightings. The five waterfowl species under consideration (Table 12-1) accounted for 50% of all sightings during the five year period.

Herring gulls (*Larus argentatus*) were the third most abundant species and the most abundant gull. Numbers sighted averaged over 4000 per year. Together with the ring-billed gull, black-backed gull and Bonaparte's gull they accounted for 26% of all bird sightings.

The sanderling (*Crocethia alba*) was the most abundant species of shorebird present; sightings averaged almost 800 per year. Other species present in large numbers included semipalmated sandpipers (*Calidris pusillus*), black-bellied plovers (*Squatarola squatarola*) and dunlins (*Calidris alpina*). Shorebirds were the least numerous of the three groups (waterfowl, gulls, shorebirds) averaging only 4% of the total sightings per year. However, during the months of May through August, shorebirds sightings represented 28% of the total.

For the four years of 1972, 1973, 1974 and 1976 the most numerous species observed in New Haven Harbor was the scaup, followed by the black duck and herring gull (Appendix Table 12-2). In 1975, however, black gulls were fourth after scaup, herring gulls and ring-billed gull (*Larus delawarensis*). For the 10 months of 1977, herring gulls were the most abundant, followed by sanderlings, scaup and ring-billed gulls.

The 1975 change in rankings in which two species of gulls moved up is probably due to the general New England-wide increase in gull numbers discussed below. Although black ducks did drop in ranking in 1975, their numbers were higher than in 1973 or 1974. The major reason for the ranking difference in 1977 was the absence of sampling during the late fall migration period when scaup and black duck numbers increase.

Waterfowl

Scaup were the most abundant and black ducks the second most abundant waterfowl species in all six years surveyed (1972-1977). Common goldeneyes were the third most abundant during four of the years, being replaced in this position by canvasbacks in 1972 and 1977 (Appendix Table 12-2).

The species of scaup observed in New Haven Harbor include both the greater scaup (*Aythya marila*) and the lesser scaup (*Aythya affinis*). It is difficult to differentiate these two species; when observed in large rafts offshore it is nearly impossible. It is likely that most of the scaup observed were greater scaup. Lesser scaup prefer freshwater areas and smaller salt water areas while greater scaup are more apt to be found on large bodies of salt water (Kortright, 1942; Collins, 1959). In addition, Benson reported that the proportion of greater to lesser scaup ranged from 6:1 near New York City to 10:1 off the coasts of Massachusetts, Connecticut and Rhode Island (Bellrose, 1968).

Greater scaup come to New Haven from breeding grounds in northwestern Canada and Alaska via one corridor stretching from Manitoba to Lake Superior, Lake Ontario and Long Island Sound. Another corridor brings the birds from Alaska to James Bay, Lake Champlain and Long Island Sound (Bellrose, 1968). Lesser scaup breed in the prairie provinces of Canada and arrive at Long Island Sound via Lake Erie and the central lakes region of New York.

The largest number of scaup observed in New Haven Harbor at one time was 10,500. Records from the Connecticut State Board of Fisheries and Game show as many as 25,000 in Long Island Sound from Pond Point to Sachem Head, Connecticut (Normandeau Associates, Inc., 1971). Furthermore, winter inventory estimates (Bellrose, 1968) for 1960-1966 showed that 225,000 scaup winter between Boston and Delaware Bay. Larger numbers of both species winter farther south.

Black ducks, although primarily ducks of fresh water, are often forced to the New England coast by winter freeze-ups of inland waters. Band returns have shown that ducks wintering in Long Island Sound arrive from breeding grounds in Labrador, Quebec and western Maine (Geis, et al., 1971). Some birds remain only a portion of the winter, flying on to the mid-Atlantic states (Addy, 1953). Approximately 60,000 winter in New Jersey alone (Bellrose, 1968); others winter south along the Atlantic coast to Florida. Aerial surveys showed 2200 as the maximum number of black ducks wintering from Pond Point to Sachem Head, Connecticut, during the winters of 1967-1970 (Normandeau Associates, Inc., 1971). The largest number observed in New Haven Harbor during this study by ground observations was 2695 in November 1976.

Common goldeneyes (*Bucephala clangula*) breed in Canada from Alaska to Newfoundland and in the United States in northern New York and northern New England. The Atlantic coastline including Long Island Sound are the primary wintering area of the entire continental population (Johnsgard, 1975). Common goldeneyes were usually present in New Haven Harbor from November through April (Appendix Table 12-2). The maximum number occurred in January 1976 when 863 were observed.

Outnumbering goldeneyes during the most recent two years of this study, yet entirely absent in 1975, were the canvasback (*Aythya valisineria*). A breeding bird of the prairie pothole region of the great plains, this species winters primarily in coastal areas. Almost one-half of the entire continental population winters in Chesapeake Bay, with wintering birds occurring north to New England and south to Florida (Johnsgard, 1975). Population levels of this species in the United States have been very low for the past 10-15 years. Estimates of total wintering canvasbacks in the United States in 1973 numbered only 215,400 (Benning, et al., 1975). A prized game bird, it has been protected by restrictive hunting regulations including closed seasons during 1960-1963 and again in 1972-1973 (Geis, 1974). Restrictive regulations and low numbers resulted in the canvasback accounting for only 0.3% of the total retrieved duck kill in the Atlantic Flyway in 1974 (Schroeder, et al., 1975). Because of these facts, it is not expected that large

numbers of canvasbacks would be observed in New Haven. The highest total yearly count for this study was 439 in 1972.

Gulls

Herring gulls, the most numerous gull species, were observed throughout the year in New Haven Harbor. A recent study by Drury and Nisbet (1972) revealed that herring gulls breed in the eastern United States from Long Island Sound to New Brunswick, in the Gulf of St. Lawrence and eastern Canada. Adults from the northern breeding colonies may migrate to winter in New England while young from all areas may migrate further south. During the breeding season some birds are normally returning to breed in the vicinity of Long Island Sound or passing through to areas farther north; some of the wintering populations would depart for breeding grounds in the north. This pattern of influx and outflow accounts for the year-round presence of herring gulls with no discernible pattern. Sightings of color-marked gulls in the vicinity of New Haven Harbor in 1961-1962 indicated they originated from breeding colonies on Cape Ann, Isles of Shoals and Outer Boston Harbor (Drury and Nisbet, 1972).

Generally, numbers of gulls in New Haven have increased during the course of this study. This probably is due to the fact that gull populations in New England have increased dramatically in the last twenty years due primarily to their widespread food habits and ability to consume human produced garbage (Kadlec and Drury, 1968). Later evidence by these same authors (1974) revealed this annual rate of population growth had slowed from the 4.5-5% rate during 1900-1965 to a .75-1.5% annual increase since 1965. Nisbet (1978) stated the herring gull breeding population in the United States now appears to be stable or decreasing, possibly due to decreased availability of fisheries wastes.

Shorebirds

The four most abundant shorebird species observed in New Haven Harbor were the semipalmated sandpiper, sanderling, dunlin and black-bellied plover. Rankings varied somewhat, with sanderlings being most abundant during the 1972-1974 period and semipalmated sandpipers most abundant during the 1975-1977 period. This change in number of sanderlings was most apparent in 1975 when numbers dropped appreciably from approximately 1000 in each of 1972, 1973 and 1974 to 50 in 1975. Their numbers then increased in 1976 and 1977. This change in rankings is most likely a function of the study design. Because of a limited number of sampling periods, coincidence plays a large role in this type of sampling program. Sanderlings which may have been present in larger numbers could have been missed on the day observations were conducted or could have been in areas of the harbor at times not coinciding with those of the observer. In addition, sightings of large flocks sometimes distort yearly averages: for example, 600 semipalmated sandpipers were observed at a single observational location in August 1975. Thus, these changes in shorebird rankings are not considered to be indicative of changes in relative abundance.

Black-bellied plovers, sanderlings, semipalmated sandpipers and sanderlings all breed in the Arctic and pass through New Haven on migration to the wintering grounds in the southern United States, the Caribbean and South America. Dunlins migrate from the Arctic to Hudson Bay and then southeast to the eastern United States, wintering farther north than many shorebird species. Black-bellied plovers pass through New Haven on their way to the West Indies and South America while the semipalmated sandpipers follow part of the large migration corridor stretching from the Rocky Mountains to the east coast (Stout, 1967).

Distribution Within the Harbor

The western side of the harbor was used extensively by waterfowl, gulls and shorebirds. Substantially fewer numbers and species utilized the eastern side (Figure 12-7). Waterfowl were found in the largest numbers in the City Point-West River Area. The average number observed in this area was approximately 7900 per year followed by over 5500 along the Long Wharf flats and almost 5000 in Area 5 south of Sandy Point (Figure 12-7 and 12-8). Yearly fluctuations in waterfowl abundance corresponded with those of total numbers.

Gulls were sighted most frequently in the Long Wharf flat area. Largest numbers occurred there during every year of the study with an average yearly figure of over 4000. The remaining western half of the harbor supported approximately the same number of gulls (Figure 12-7 and 12-8).

Shorebirds were found in highest average numbers on the Long Wharf flats followed by the Sandy Point and City Point areas. However, a high of 8293 sightings on Long Wharf in 1973 resulted in a disproportionately affected average (Figure 12-8). Similar average numbers of shorebirds were observed in Area 5 during the other four years of the study (Figure 12-7 and 12-8).

Although waterfowl were found in largest numbers in Area 4 (based on averages for the five-year period), there were species differences. Areas 4 and 5 (Sandy Point) were most important to the diving ducks (scaup, canvasback and goldeneye) while Area 3 (Long Wharf) and 4 were used heavily by black ducks. The only year in which the most waterfowl were observed in Area 5 was 1975; this year also recorded the largest number of scaup in the harbor, indicating the preference for the area of open water by this species.

Total yearly averages for both gulls and shorebirds were highest in Area 3 followed by Area 5. For both groups, highest numbers

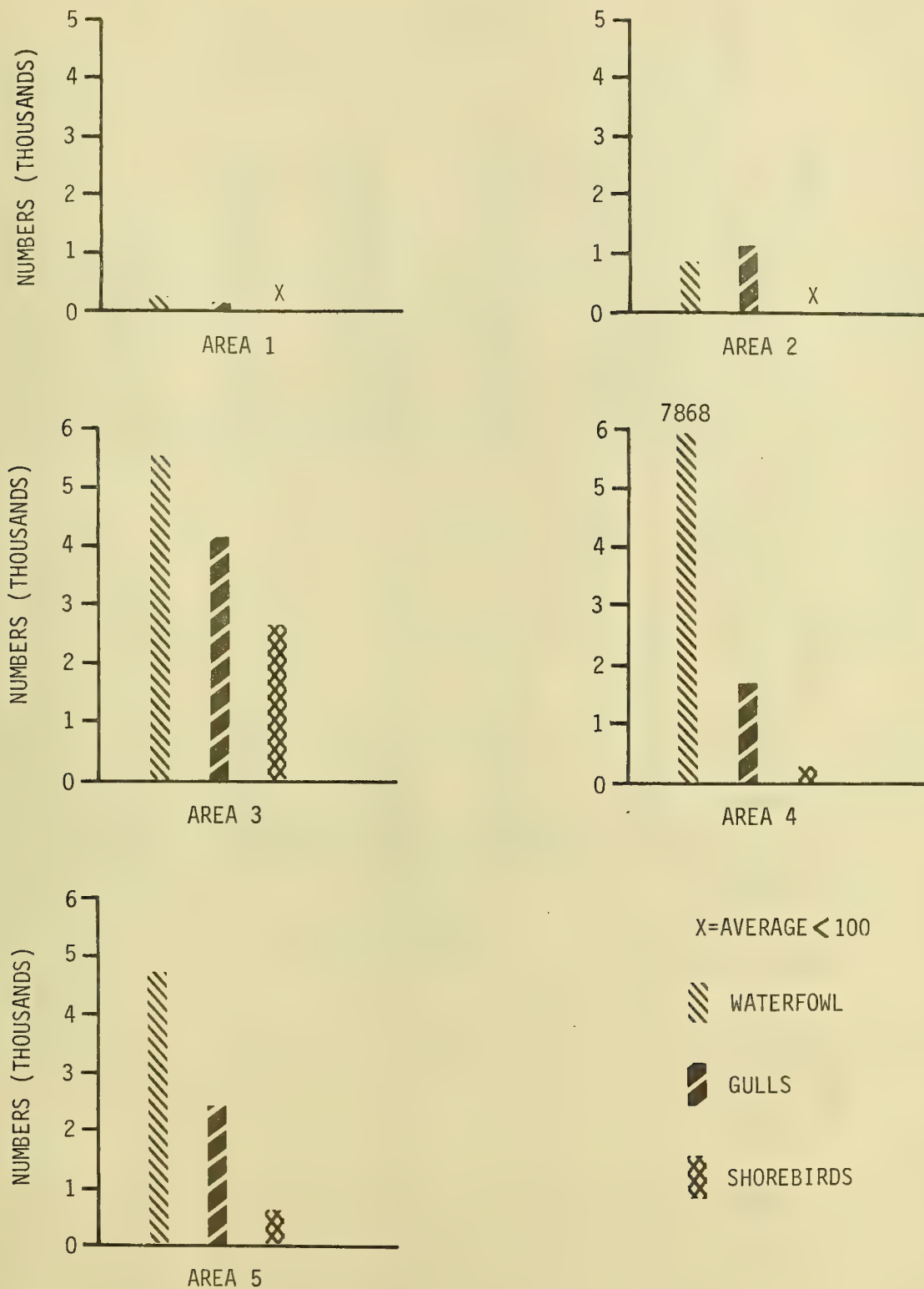


Figure 12-7. Average number of waterfowl, gulls and shorebirds observed at various areas of New Haven Harbor from 1972-1976 surveys. New Haven Harbor Ecological Studies Summary Report, 1979.

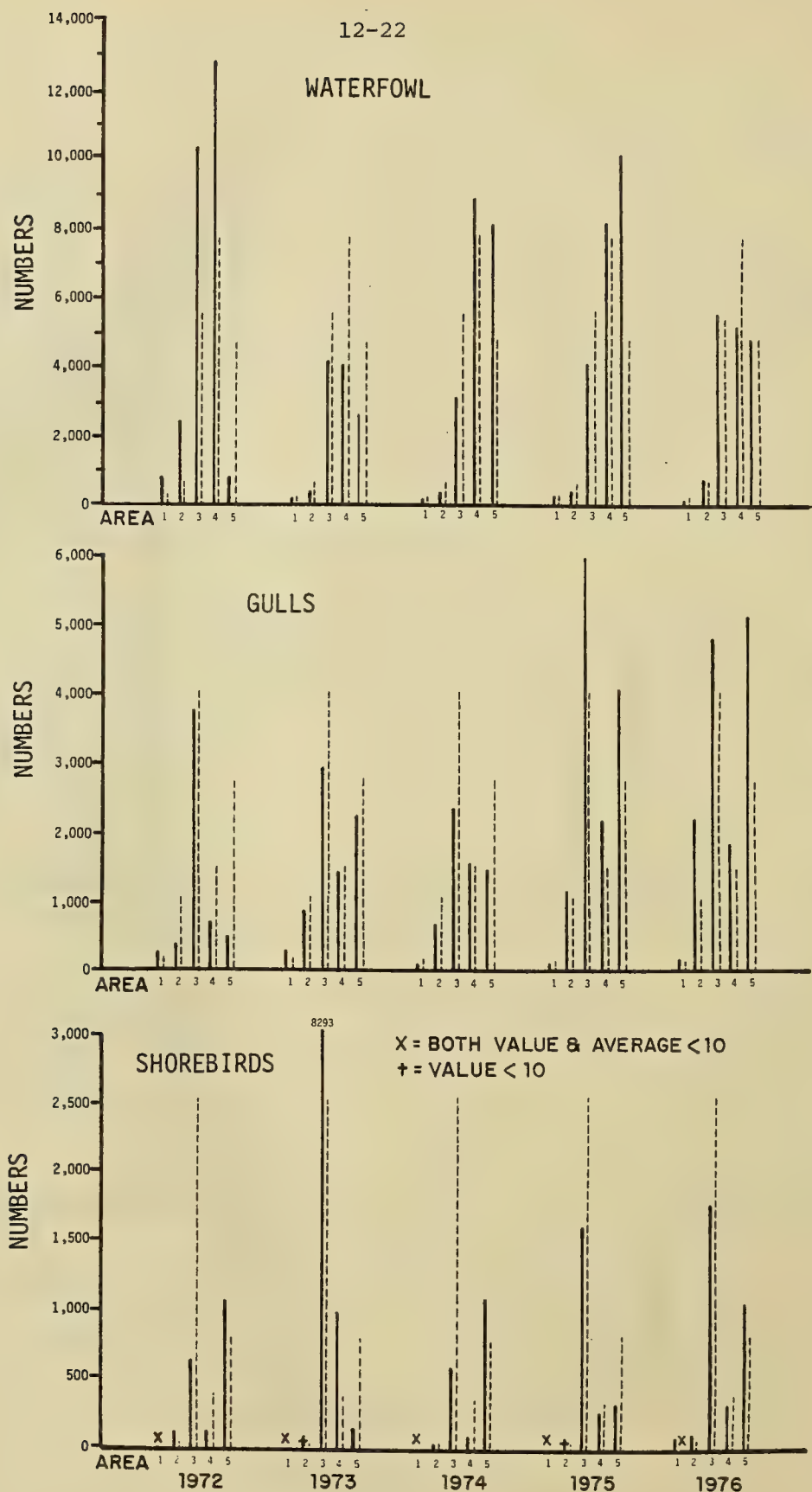


Figure 12-8. Numbers of waterfowl, gulls and shorebirds observed at various areas of New Haven Harbor, 1972-1976. Dashed lines represent five year means. New Haven Harbor Ecological Studies Summary Report, 1979.

for four of the five years occurred in Area 3; for the other year, highest numbers occurred in Area 5.

The distribution of birds within the harbor is related to the availability of feeding and resting habitat. The greater scaup, a diving duck, feeds by diving in water to depths of two to ten feet and rarely ventures onto land. This species is dependent on animal food for part of its diet and heavily utilizes animal material when inhabiting salt water. Cronan and Halla (1968) examined the gizzards of 157 greater scaup shot on or near the Rhode Island coast during the months of November, December and January, 1954-1957. Plant material occurred in 31.2% of the gizzards but accounted for only 1.2% of the total food volume. In contrast to this, animal material occurred in 94.3% of the gizzards and accounted for 98.8% of total food volume. The most important animal foods were the soft-shelled clam (*Mya arenaria*), eastern mud snail (*Ilyanassa obsoleta*) and the dwarf surf clam (*Mulinia lateralis*).

The lesser scaup appears to consume more plant material than the greater scaup (Kortright, 1942). Birds collected throughout the country revealed 78% of the fall diet and 67% of the winter diet to be composed of plant life (Martin et al., 1951); however, Rogers and Korschgen (1966) believe that the lesser scaup feeds primarily on animal material. Of 27 gizzards collected on the Rhode Island coast in winter, animal material was found in 88.9% of all gizzards and totaled 85.1% by volume; the dominant species found in these analyses included the eastern mud snail, alternate bittium (*Bittium alternatum*) and the lunar dove-shell (*Mitrella lunata*) (Cronan and Halla, 1968).

The third diving duck found in significant numbers in New Haven Harbor is the common goldeneye (*Bucephala clangula*). This species is also heavily dependent on animal food with 77% of the fall and winter diet being composed of animal material (Martin et al., 1951). The Rhode Island study by Cronan and Halla (1968) found animal material in 54.6% of all gizzards; half the 82.4% volume of animals fed upon was unidentified decapods, primarily crabs. Stott and Olson (1973) concluded the major animal component of the diets of common goldeneye found off the

New Hampshire coastline was isopods (*Idotea baltica*), amphipods (*Ampithoe rubricata*) and rock crab (*Cancer irroratus*).

The black duck is a member of the dabbling or puddle-duck group. These birds feed on material from the bottom by tipping in water usually less than 3 feet deep. Black ducks consume a higher proportion of plant material than do the diving ducks. Martin *et al.* (1951) reported plants comprised 86% of the fall diet and 71% of the winter diet. Black ducks wintering in coastal New England, however, rely more heavily on animal life. Food habit studies conducted in coastal Maine revealed 73% of the fall diet and 87% of the winter diet to be animal matter; gastropods and pelecypods were the most important items (Mendall, 1949). Black ducks wintering on or near the coast of Rhode Island were found to contain 28% animal foods by volume and 58% by occurrence (Cronan and Halla, 1968). This smaller figure may be due to less harsh conditions, more open fresh water and hence more plant food availability than in Maine.

The herring gull is classified as an omnivore and scavenger. Food items include small fish, crustaceans, molluscs, insects, and bird eggs as well as garbage (Forbush, 1925; Martin *et al.*, 1951).

The various species of sandpipers and plovers found in New Haven Harbor have similar food habits. Almost all food consumed is animal material consisting of insects, crustaceans, molluscs, marine worms and clam worms (Forbush, 1925; Collins, 1959; Martin *et al.*, 1951).

Benthic intertidal studies conducted as part of the New Haven Harbor Station Ecological Monitoring Studies (1974c, 1975, 1976, 1977) revealed the four most abundant invertebrate species in the intertidal Long Wharf area to be members of the phylum Annelida. Present in much smaller numbers were horseshoe crabs (*Limulus polyphemus*), soft-shell clams (*Mya arenaria*), jingle shells (*Gemma gemma*), eastern mud snails (*Ilyanassa obsoleta*) and unidentified copepods. Fish species collected by seining in shallow waters of New Haven Harbor yielded large

numbers of striped killifish (*Fundulus majalis*) and smaller numbers of Atlantic silversides (*Menidia menidia*). Both species can be found in waters near shore and are sometimes trapped in pools as the tide recedes.

The above mentioned species of invertebrates and fish would provide food for gulls and shorebirds. The large number of annelid worms is of particular importance to the shorebirds and they also provide some food for gulls. The molluscs, including the eastern mud snail, and crustaceans would provide food for waterfowl, shorebirds and gulls. The fish present would be utilized almost exclusively by the gulls. Because of the abundance of marine worms and scarcity of molluscs, crustaceans and gastropods at Long Wharf area, the area would be expected to be most utilized by shorebirds. Gulls would feed in the area to an intermediate extent and waterfowl least of all. Comments recorded on early data sheets lend support to this assumption; there was no mention of waterfowl feeding but several observations of shorebird feeding. Personal observations in January 1975, however, indicated that the Long Wharf area was used by feeding black ducks as well as gulls and shorebirds.

The other main utilization of the western side of New Haven Harbor appears to be for resting and shelter. The winter winds are frequently out of the north and northwest. Comments on early data sheets have referred to black ducks huddling near the shore at Long Wharf to get out of the wind. The area at the West River mouth was also observed to be utilized by large numbers of waterfowl and gulls during January 1975. Comments and personal observation concur on the fact that gulls used the entire western harbor for resting and were not always exhibiting feeding activity.

The large number of scaup observed in Areas 3 and 4 spend most of their time in large rafts offshore. Being diving ducks they would not normally venture onto the flats to feed. Goldeneyes, canvasback and buffleheads display similar behavior. Since at low tide a large part of New Haven Harbor is less than 10 feet deep, it is possible for these ducks to feed in areas far from shore.

Observations of Rare or Uncommon Species

Since the beginning of this study in 1971, species have been sighted that are noteworthy (Table 12-4) because they are rare throughout their range or because New Haven Harbor is near the limits or outside their normal range.

Baird's sandpiper (*Erolia bairdii*), golden plover (*Pluvialis dominica*), pectoral sandpipers (*Erolia melanotos*) and white-rumped sandpiper (*Erolia fuscicollis*) have been listed as regular but uncommon fall migrants and rare spring migrants along the eastern coast (Bull, 1974; Sage et al., 1913; Stout, 1967; Robbins et al., 1966). This is believed to be due primarily to the differences in their seasonal migration flights; spring flights are through the interior of the continent while fall flights follow the coast (Bent, 1929; Stout, 1967; Bull, 1974; Robbins et al. (1966).

The black tern (*Chilodonia niger*), primarily a bird of the prairies is also seen on the coast only in the fall (Collins, 1959). Forster's tern (*Sterna forsteri*) ranges from uncommon to common as a fall migrant (Bull, 1974) and is listed as rare on coastal beaches (Robbins et al., 1960). The merlin (*Falco columbarius*) is listed as a common fall coastal migrant but very rare in winter (Bull, 1974; in addition, this species is uncommon throughout its range (Robbins et al., 1977). The marbled godwit (*Limosa fedua*) is also a regular but uncommon fall migrant, largely confined to the south shore of Long Island and areas to the south (Bull, 1974).

Two species, the cattle egret (*Bubuleus ibis*) and the glossy ibis (*Plegadis falcinellus*), have only recently occurred in the New Haven area. Cattle egrets, originally from Africa, became established in South America and then expanded through the West Indies to North America. Bert (1926) did not list this species as occurring in the United States and it is believed to have first established itself in the early 1950's (Collins, 1959). The first breeding record in New Jersey occurred in

TABLE 12-4. RARE OR UNUSUAL SPECIES OBSERVED IN NEW HAVEN HARBOR, 1971-1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

<u>COMMON NAME</u>	<u>SCIENTIFIC NAME</u>
Gyr Falcon	<i>Falco rusticolis</i>
Merlin	<i>Falco columbarius</i>
Cattle egret	<i>Bubulcus ibis</i>
Glossy ibis	<i>Plegadis falcinellus</i>
Clapper rail	<i>Rallus longirostris</i>
Golden plover	<i>Pluvialis dominica</i>
Wilson's plover	<i>Charadrius wilsonia</i>
Marbled godwit	<i>Limosa fedua</i>
Pectoral sandpiper	<i>Erolia melanotos</i>
White-rumped sandpiper	<i>Erolia fuscicollis</i>
Baird's sandpiper	<i>Erolia bairdii</i>
Glaucous gull	<i>Larus hyperboreus</i>
Forster's tern	<i>Sterna forsteri</i>
Black tern	<i>Chlidonias niger</i>
Black skimmer	<i>Rynchops nigra</i>

1958, on Long Island in 1970 and in Connecticut in 1971 (Bull, 1974). The species is now established and not considered rare in southern New England. The glossy ibis is believed to have established itself in North America from its original breeding grounds in Africa in a manner similar to the cattle egret. The first breeding record of this species north of Florida occurred in 1940 and the first record on Long Island in 1961 (Bull, 1974). The species has since expanded and now breeds on the Isles of Shoals, off the coast of New Hampshire (Parsons *et al.*, 1978).

A number of the species recorded were at the limits of their normal ranges. The gyrfalcon (*Falco rusticolis*) is an arctic bird, rarely occurring south of Canada (Robbins *et al.*, 1966). New Haven is near the southern range of the glaucous gull (*Larus hyperboreus*) and near the northern range of the clapper rail (*Rallus longirostris*), Wilson's plover (*Charadrius wilsonia*) and skimmer (*Rhynchops nigra*) (Bull, 1974; Collins, 1959; Sage *et al.*, 1913; Peterson, 1947).

ANALYSIS OF IMPACTS OF NHHS OPERATION ON AVIFAUNA

New Haven Harbor Station has the potential to affect avian populations within New Haven by: 1) inducing avoidance of or attraction to the heated effluent, 2) detrimentally affecting organisms serving as avian food sources, or 3) disturbance by increased ship traffic and interference of the stack and/or transmission lines with flight patterns.

Possible impacts were evaluated through inspection of the data prior to and after August 29, 1975, when full-time plant operation commenced, attention being focused on changes in numbers of birds and geographical distribution. Possible long-term and subtle effects were evaluated through inspection of the data concerning fish and intertidal and subtidal benthos as these are important food sources for the birds in New Haven Harbor. Any changes in population or distribution of these organisms were noted.

Abundance

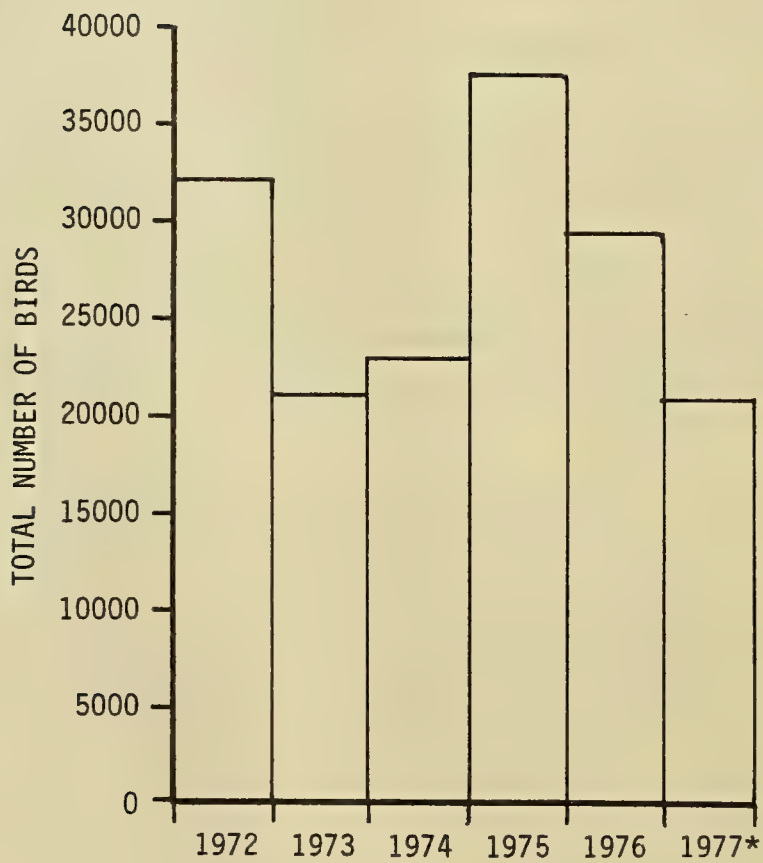
For the 1972-1977 period, overall abundance of birds in New Haven has fluctuated as depicted in Appendix Table 12-2 and Figure 12-9. Lowest numbers occurred in 1973 and 1974, prior to plant operation while highest numbers were observed in 1972 also prior to plant operation, in 1975 and in 1976, after plant operation began. In addition, the ten months of data collected in 1977 revealed bird populations to be higher than those observed in all of 1973 and almost as high as in all of 1974. From these data, it appears the New Haven Harbor Station is not having a detrimental effect on numbers of birds utilizing New Haven Harbor.

As depicted in Appendix Table 12-2, the seasonal abundance of birds in New Haven Harbor has remained consistent during the course of the study. Numbers have generally been highest in late fall and winter, lowest in early to mid-summer and intermediate during other times of the year. As explained in the "Abundance" Section, this is due to the migratory habits of the birds and is not affected by operation of the New Haven Harbor Station.

In addition, comparison of total birds observed in each of three months (January, July and October) throughout the years 1972-1977 shows that not only have there been fluctuations in numbers, but more birds have been observed during these months since plant operation commenced than prior to plant operation (Figure 12-10).

Waterfowl

Waterfowl numbers within New Haven Harbor have fluctuated from year to year with no discernible pattern (Figure 12-11). The highest number was recorded in 1972, and the lowest number in 1973, both prior to plant operation. Data for the months of October, November and December in 1975 and 1976 (following plant startup) show typical number of waterfowl within New Haven Harbor for this time of year (Appendix Table 12-2).



* ten months only 1977

Figure 12-9. Total number of birds observed in New Haven Harbor for each year, 1972-1977. New Haven Harbor Ecological Studies Summary Report, 1979.

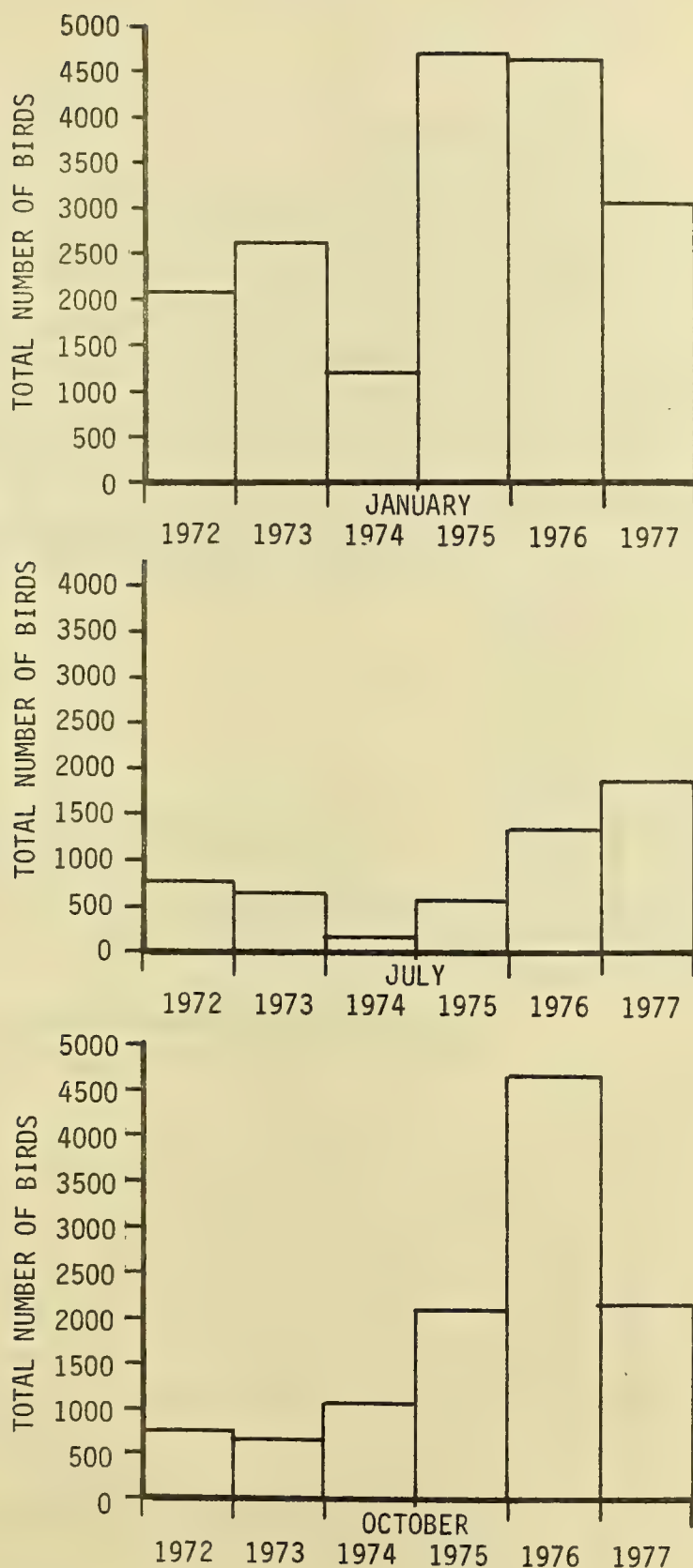
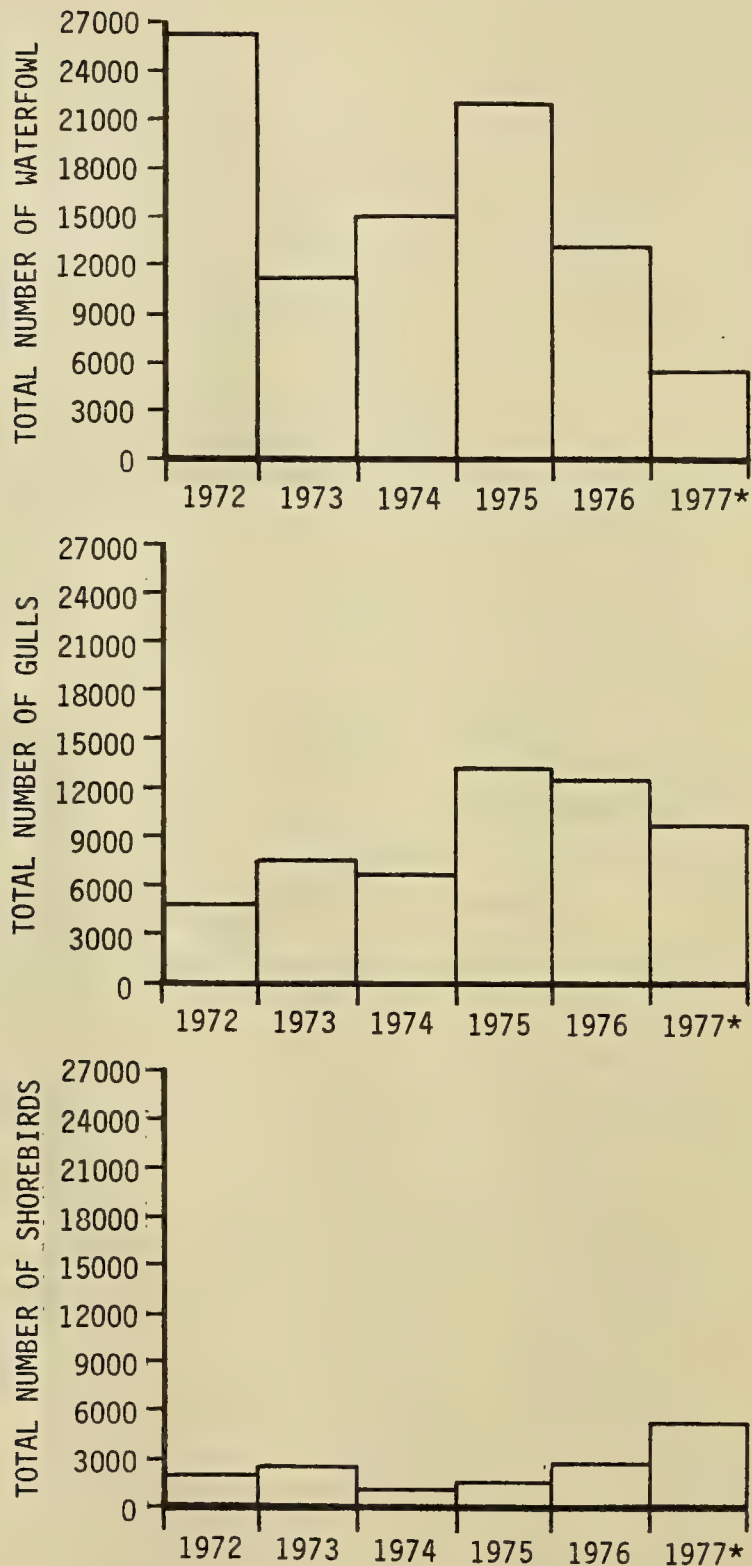


Figure 12-10. Total number of birds observed in January, July and October for each of the years 1972-1977. New Haven Harbor Ecological Studies Summary Report, 1979.



* ten months data only 1977

Figure 12-11. Total number of waterfowl, gulls and shorebirds observed New Haven Harbor for the years 1972-1977. New Haven Harbor Ecological Studies Summary Report, 1979.

Additional insight into the possible effects of the plant on New Haven Harbor can be gained through comparison of data from this study with data from surveys outside New Haven Harbor. Waterfowl numbers in New Haven are dominated by scaup and their abundance or scarcity is reflected in the total waterfowl figures. Scaup in the New York portion of Long Island Sound are censused each winter by the New York Department of Environmental Conservation. Comparison of their data for the years 1972 - 1976 shows fluctuations similar to those observed in this study (Figure 12-12). It appears therefore, that the changes in scaup populations within New Haven Harbor are not due to any factors from within the harbor.

Gulls

Number of gulls has also fluctuated, with a general trend toward increasing populations (Figure 12-11). This is probably due to the New England-wide increase in gull populations discussed under the "Characterization of New Haven Harbor Avifauna."

Shorebirds

Lowest numbers of shorebirds were observed in 1974, prior to plant operation and highest numbers during 1976 and the ten months of 1977 (Figure 12-11). This change and the fluctuations in numbers are probably unrelated to New Haven Harbor Station and instead are due to the factors discussed in the "Characterization" section - i.e. tide level, coincidence, and species-wide population fluctuations.

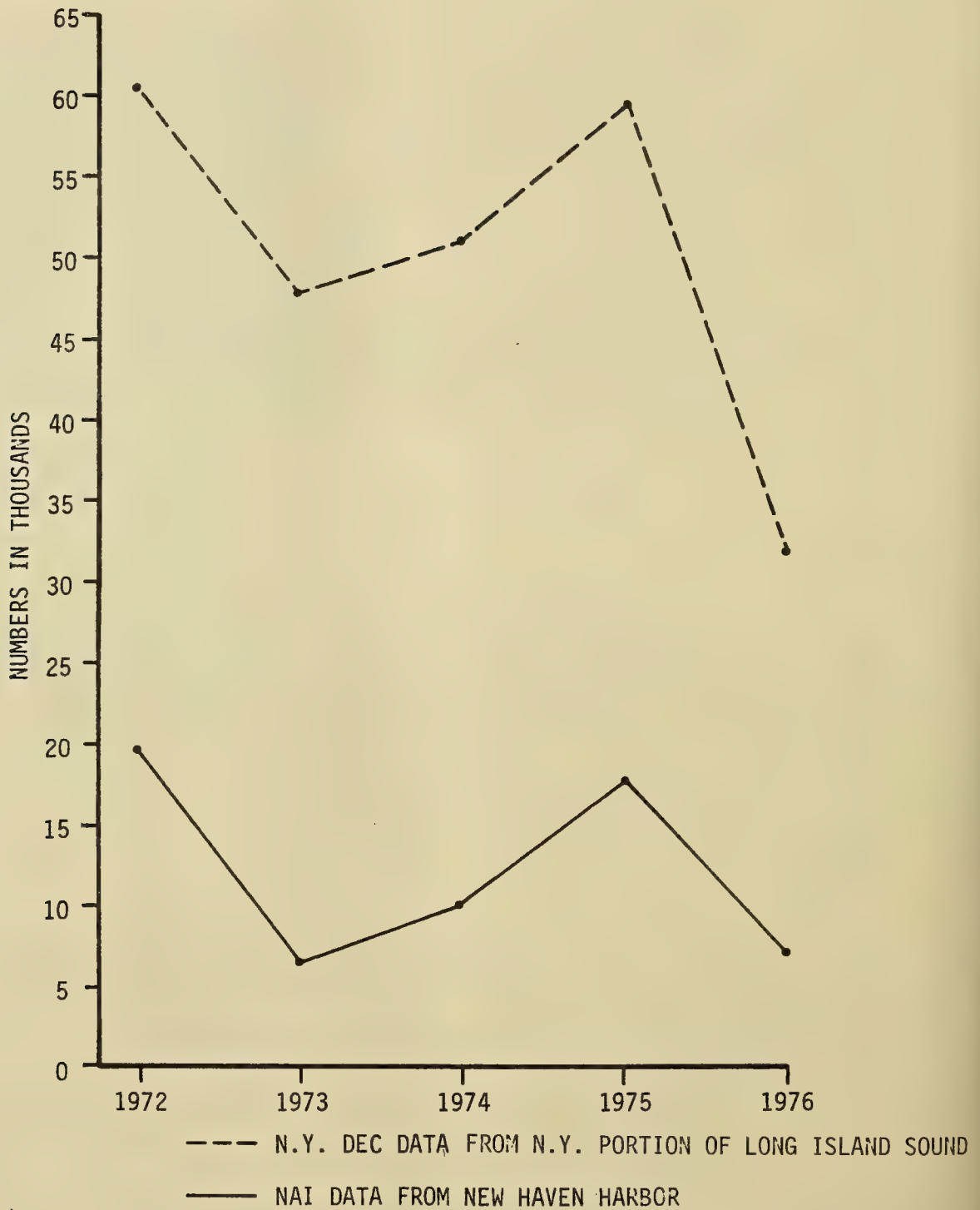


Figure 12-12. Comparison of numbers of scaup observed in New York portion of Long Island Sound and in New Haven Harbor, 1972-1976. New Haven Harbor Ecological Studies Summary Report, 1979.

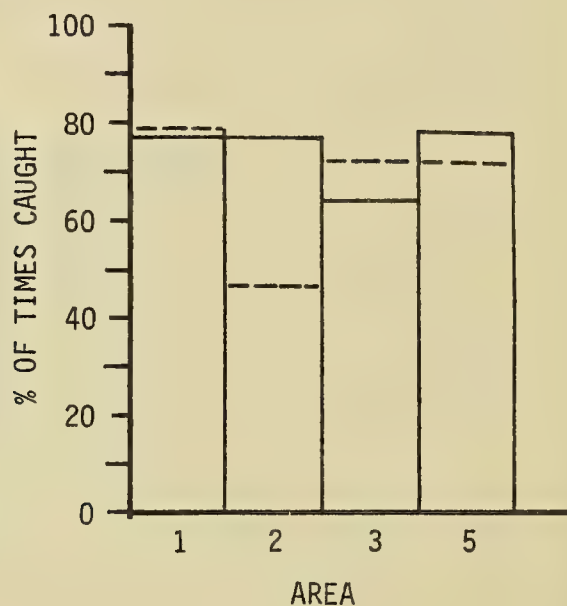
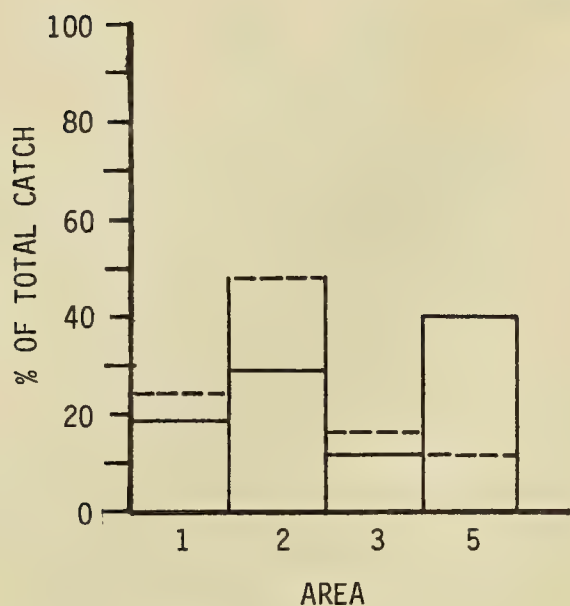
Impacts on Avian Food Sources*Fish*

As discussed in the "Characterization" section the marine organisms of New Haven Harbor provide food for the avian population. Small fish are utilized by gulls and diving ducks, intertidal benthic organisms by shorebirds, gulls and dabbling ducks and subtidal benthos by diving ducks. As such, it is necessary to examine any changes in these organisms since operation of the New Haven Harbor Station commenced.

Silversides (*Menidia* spp.) and killifish (*Fundulus* spp.) and other small fish found near shore are suitable avian prey species. Comparisons of preoperational and operational data for these fish appear in Figure 12-13. The percent of total silverside catch increased on the eastern side of the harbor as well as on the Long Wharf area after plant start-up and declined in the Sandy Point area. Frequency of capture increased in the Lighthouse Point, Long Wharf and Sandy Point areas and declined in the New Haven Harbor Station area. (There was no sampling station in Area 4).

Killifish also showed slight changes in distribution. Percent of total catch increased at the Long Wharf flats area and decreased elsewhere. Frequency of capture declined in all areas sampled.

These changes in distribution are probably not important. It should be noted that percent of total catch for both species increased in the Long Wharf area; this is where the largest number of gulls occurred and where large numbers of shorebirds and waterfowl feed. A similar study of power-plant impacts on Lake Erie found the heated effluent attracted fish eaten by common goldeneyes, herring gulls, ring-billed gulls and common mergansers (*Mergus merganser*). In New Haven, percent of total catch for both silversides and killifish increased in Area 2, which is near the New Haven Harbor Station, and aggregations of mergansers, gulls and cormorants have been observed feeding near the New Haven Harbor Station discharge (Pease, pers. obs. 1976, 1977).

MENIDIA SPP.

— BEFORE SEPTEMBER 1975

- - - AFTER SEPTEMBER 1975

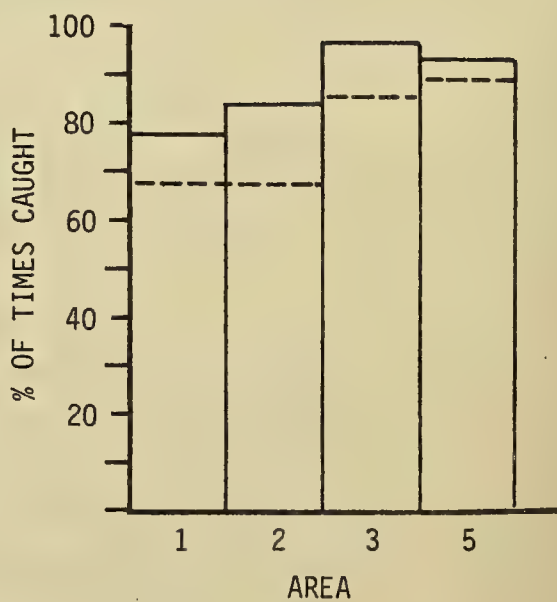
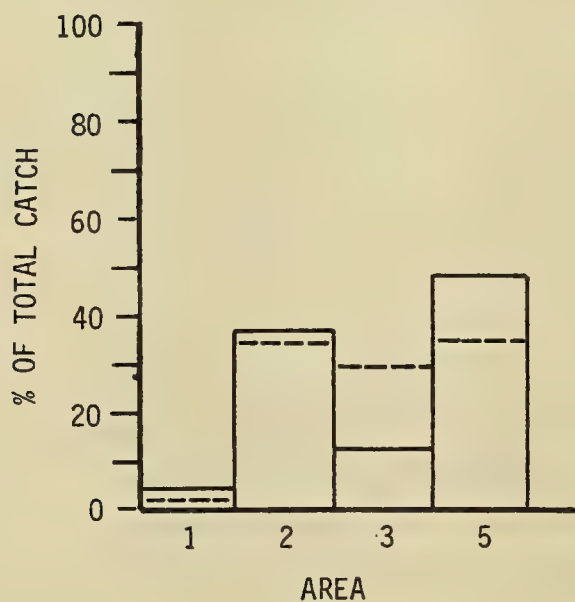
FUNDULUS SPP.

Figure 12-13. Preoperational and operational comparisons of percent of total catch and frequency of capture. New Haven Harbor Ecological Studies Summary Report, 1979.

Intertidal Benthos

Overall abundances of intertidal benthic organisms at East Shore, Long Wharf and Sandy Point for the 1971-1977 period are presented in Section 7.0. There are no substantial differences in the preoperational and operational populations at these three sites. Species diversity (number of taxa collected) also remained similar in pre and post-operational years. In general, however, highest number of taxa were found in the Sandy Point area, followed by Long Wharf and East Shore.

Intertidal samples in the Sandy Point area were dominated numerically by the gem clam (*Gemma gemma*), soft-shell clam (*Mya arenaria*) and mud snail (*Ilyanassa obsoleta*). Also present in large numbers were polychaete worms, *Nereis* spp. and those of the family Spionidae and Cirratulidae. Data indicate that there have been no major changes in total numbers or species composition during the 1971-1977 period. Polychaete worms and molluscs have been present both prior to and after plant start-up. Gem clams have not been found in samples collected after May 1974, when the sampling transect was changed. The absence of this species is probably due to its localized breeding habits and the change in substrate of the new transect.

The bivalves *Mya arenaria* and *Gemma gemma* and polychaete worms of the genus *Nereis* dominated the benthic fauna at the Long Wharf flats. With the exception of reduced numbers of all species in October 1976 and May 1977, numbers and species diversity have not changed substantially. This decline during these two sampling periods is not believed to be significant and is explained in Section 7.0.

The East Shore area was generally the lowest both in number of species and overall abundance. Polychaetes were the most consistently present organisms, while bivalves also occurred. Both total numbers and numbers of species fluctuated both before and after plant start-up.

Subtidal Benthos

Results from data collected under the supervision of NAI (1973-1977) for United Illuminating and from studies conducted by Rhoads and Michael (1975, 1976, 1977) show the eastern half of New Haven Harbor to be dominated by polychaete worms with fewer numbers of bivalves and amphipods also present. The subtidal areas adjacent to the Long Wharf flats are dominated by pollution tolerant polychaetes and small numbers of clams and snails. Data for the western side of the outer harbor are scarce but it is likely these areas also are dominated by polychaete worms.

There appear to have been no significant changes in subtidal benthic populations since plant start-up. Annual variations in populations have been continuous since the beginning of the study and do not appear to have been affected by plant operation. [The only exception is a chronic decrease in inner harbor populations during August; the exact extent and cause of this is presently unclear.]

SUMMARY

Bird utilization of New Haven Harbor was typical of a large, shallow urbanized estuary: the harbor provided shelter and feeding grounds for shorebirds, gulls and migratory waterfowl. There was no indication that any portion of New Haven Harbor served as a nesting area for birds which utilize the shallows for feeding and shelter from storms. Overall bird abundance fluctuated similarly both prior to and after plant start-up while seasonal abundance remained fairly constant. Number of waterfowl fluctuated with no discernible pattern from 1971-1977 and did not appear to be affected by plant operation. Gull numbers also fluctuated with a general trend toward increasing populations. Shorebird numbers also fluctuated, with highest numbers observed in 1976 and 1977.

Populations of prey species of fish, and intertidal and subtidal benthos showed considerable fluctuations during the course of the study, but maintained sufficient abundance to serve as a substantial food resource for birds.

The height of the transmission line towers and the large horizontal distance covered by the power lines pose a potential hazard to birds. If the flight patterns to the Long Wharf flats, New Haven Harbor Station area or areas north of the transmission lines were such that large numbers of birds passed through the area, collisions could occur, resulting in injury or death.

The main areas utilized by avian populations in New Haven Harbor (Long Wharf flats, Sandy Point and mouth of the West River) are south of the transmission line. Little habitat is provided by either the Mill or Quinnipiac Rivers north of the Connecticut turnpike bridge. Therefore, bird movement from or to these areas should be minimal and the transmission lines and towers should not have any appreciable effect on avian populations.

In summary, the construction and operation of New Haven Harbor Station does not appear to have diminished the harbor's value as avian feeding, resting or wintering habitat. Furthermore, there were no apparent plant caused effects on food resources available to birds using the harbor. In short, there is no evidence that the New Haven Harbor generating station has had any adverse effect on the local populations of waterfowl, gulls and shorebirds.

LITERATURE CITED

- Addy, C.E. 1953. Fall migration of the black duck. U.S. Dept. Inter. Fish and Wildl. Serv. Spec. Sci. Rpt. Wildl. No. 19. 63pp.
- Bellrose, F.C. 1968. Waterfowl migration corridors east of the Rocky Mountains in the United States. Ill. Nat. Hist. Surv. Biol. Note No. 61. 24pp.
- Bent, A.C. 1929. Life histories of North American shorebirds. Vol. I and II. Smithsonian Institute Bull. 146. 420 & 411pp.
- _____. 1926. Life histories of North American marsh birds. Dover Publ. N.Y. 392pp.
- Bradstreet, M.S.W., G.W. Page and W.G. Johnston. 1977. Shorebirds at Long Point, Lake Erie, 1977-1971: Seasonal occurrence, habitat preference and variation in abundance. Can. Field Natur. 91(3): 225-236.
- Bull, J. 1974. Birds of New York State. Doubleday Nat. Hist. Press Garden City, N.Y. 655pp.
- Burger, Joanna, M.A. Howe, D.C. Hahn and Julia Chase. 1977. Effects of tide cycles on habitat selection and habitat partitioning by migrating shorebirds. The Auk 94:743-758.
- Collins, H.H., Jr. 1959. Complete field guide to American wildlife. Harper and Row, N.Y. 681pp.
- Cronan, J.M. and B.F. Halla. 1968. Fall and winter foods of Rhode Island Waterfowl. R.I. Dept. Nat. Resour. Div. of Conserv. Wildl. Pamphlet No. 7. 40pp.
- Drury, W.H. 1974. Population changes in New England seabirds. Bird-Banding 45(1):1-15.
- _____. and I.C.T. Nisbet. 1972. The importance of movements in the biology of herring gulls in New England. Pages 173-211 IN: population ecology of migratory birds: A Symposium. U.S. Dept. Inter. Bur. of Sport Fish. and Wildl. Res. Rep. 2. 278pp.
- _____. and J.A. Kadlec. 1974. The current status of the herring gull population in the Northeastern United States. Bird-banding 45(4):297-306.
- Finch, D.W. 1976a. The Fall Migration: August 1-November 30, 1975. Northeastern Maritime Region - American Birds 30(1):29-36.

- _____. 1976b. The Spring Migrations: April 1-May 30, 1976c.
Northeastern Maritime Region. American Birds 30(4):811-815.
- _____. 1977. The Fall Migration: August 1-November 30, 1976.
Northeastern Maritime Region. American Birds 31(2):225-231.
- Forbush, E.H. 1925. Birds of Massachusetts and other New England
states. Mass. Dept. Agric. Vol. I. 481pp.
- Geis, A.D., R.I. Smith and J.P. Rogers. 1961. Black duck distribution,
harvest characteristics and survival. U.S. Dept. Inter. Bur. Sport
Fish and Wildl. Spec. Sci. Rep. Wildl. No. 139. 241pp.
- _____. 1974. Breeding and wintering areas of canvasbacks harvested
in various states and provinces. U.S. Dept. Inter. Fish and Wildl.
Serv. Spec. Sci. Rpt. Wildl. No. 185. 78pp.
- Heilbrun, L.H. 1976. The Seventy-Sixth Audubon Christmas Bird Count.
American Birds 30(2):245.
- _____. 1977. The Seventy-seventh Audubon Christmas Bird Count.
American Birds. 31(4):496-497.
- Johnsgard, P.A. 1975. Waterfowl of North America Indiana University
Press. Blomington. 575pp.
- Kadlec, J.A. and W.H. Drury. 1968. Structure of the New England herring
gull population. Ecology 49(4):644-645.
- Kortright, F.H. 1942. The ducks, geese and swans of North American.
Stackpole Co., Harrisburg, Pa. 476pp.
- Martin, A.C., H.S. Zim and A.L. Nelson. 1951. American wildlife and
plants. A guide to wildlife food habits. Dover Publications, N.Y.
500pp.
- McGillvrey, F.B. 1967. Food habits of sea ducks from the northeastern
United States. The Wildfowl Trust 18th Annual Rpt.:142-145.
- Nisbet, I.C.T. 1978. Recent changes in gull populations in the western
North Atlantic. Ibis 120: 129-130.
- _____. 1973. Terns in Massachusetts. Present numbers and historical
changes. Bird-banding 44(1):27-55.
- Normandeau Associates, Inc. 1971. Waterfowl distribution and occurrence
New Haven Harbor and Vicinity. 5pp.
- _____. 1973. New Haven Harbor ecological studies. 208pp.
- _____. 1974a. Coke Works ecological monitoring studies. Annual
Rep. 1972-1973. 215pp.

- Normandeau Associates, Inc. 1974b. Coke Works ecological monitoring studies. Interim Rep. May - December, 1973. 199pp.
- _____. 1974c. Ecological studies conducted at selected sites in New Haven Harbor. Conn. Review Draft. 102pp.
- Parsons, Brinckerhoff, Quade and Douglas and Normandeau Associates, Inc. 1978. Candidate Environmental Impact Statement for Project P-152. Dredging Portsmouth Naval Shipyard, Portsmouth, N.H. Contract # N62472-76-C-1069. Dept. of Navy. NAVFACENG COM, Philadelphia.
- Reed, L.W. 1971. An ecological evaluation of a thermal discharge. Part VI: Use of Western Lake Erie by migratory and wintering waterfowl Mich. State Univ. Instit. Nat. Res. Tech. Rpt. No. 18, Thermal Discharge Series. 71pp.
- Robbins, C.S., B. Brunn and H.S. Zim. 1966. A guide to field identification of birds of North America. Golden Press, N.Y. 340pp.
- Roger, J.P. and L.J. Korschgen. 1966. Foods of lesser scaup on breeding, migration and wintering areas. J. Wildl. Manage. 30:258-264.
- Sage, J.H., L.B. Bishop and W.P. Bliss. 1913. The birds of Connecticut. State Geological and Natural History Survey, Hartford. 370pp.
- Stott, R.S. and D.P. Olson. 1973. Food habitat relationship of sea ducks on the New Hampshire Coastline. Ecology 54(5):996-1007.
- Stout, G. D. (ed.). 1967. The shorebirds of North America. Viking Press, N.Y. 270pp.
- Vickery, P.D. 1977a. The Spring Migration: March 1-May 31, 1977. Northeastern Maritime Region. American Birds 31(5):972-977.
- _____. 1977b. The Winter Season: December 1, 1976 - February 28, 1977. Northeastern Maritime Region. American Birds. 31(3): 304:309.

APPENDICES

APPENDIX TABLE 12-1. LIST OF AVIAN SPECIES ENCOUNTERED IN NEW HAVEN HARBOR, JUNE 1971 THROUGH OCTOBER 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

		YEAR	71	72	73	74	75	76	77
PHYLUM:	CHORDATA								
Subphylum:	Vertebrata								
Class:	Aves (Birds)								
Order:	Gaviiformes (Loons)								
	<i>Gavia immer</i> - Common loon		✓	✓	✓	✓	✓	✓	✓
	<i>Gavia stellata</i> - Red-throated loon								✓
Order:	Podicipediformes (Grebes)								
	<i>Podiceps auritus</i> - Horned grebe		✓	✓	✓	✓	✓	✓	✓
Order:	Pelecaniformes (Pelicans and Allies)								
	<i>Phalacrocorax</i> spp. - Cormorant		✓	✓	✓	✓	✓	✓	✓
Order:	Anseriformes (Waterfowl)								
	<i>Anas acuta</i> - Pintail								✓
	<i>Anas americana</i> - American wigeon							✓	✓
	<i>Anas carolinensis</i> - Great-winged teal							✓	✓
	<i>Anas platyrhynchos</i> - Mallard	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Anas rubripes</i> - Black duck	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Aythya affinis</i> - Lesser scaup	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Aythya marila</i> - Greater scaup	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Aythya valisineria</i> - Canvasback		✓	✓	✓	✓	✓	✓	✓
	<i>Branta bernicla</i> - Atlantic brant				✓				
	<i>Branta canadensis</i> - Canada goose				✓	✓	✓	✓	✓
	<i>Bucephala albeola</i> - Bufflehead	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Bucephala clangula</i> - Common goldeneye	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Bucephala islandica</i> - Barrow's goldeneye		✓						✓
	<i>Chen hyperborea</i> - Snow goose								✓
	<i>Clangula hyemalis</i> - Oldsquaw	✓	✓	✓					✓
	<i>Cygnus olor</i> - Mute swan			✓	✓	✓	✓	✓	✓
	<i>Mergus serrator</i> - Red-breasted merganser	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Melanitta nigra</i> - Common scoter		✓						✓
	<i>Oxyura jamaicensis</i> - Ruddy duck							✓	
Order:	Ciconiiformes (Herons and Allies)							✓	
	<i>Ardea herodias</i> - Great blue heron							✓	✓
	<i>Bubulcus ibis</i> - Cattle egret							✓	✓
	<i>Butorides virescens</i> - Green heron						✓	✓	✓
	<i>Casmerodius albus</i> - Great egret				✓		✓	✓	✓
	<i>Florida caerulea</i> - Little blue heron						✓	✓	✓
	<i>Leucophox thula</i> - Snowy egret			✓	✓		✓	✓	✓
	<i>Nycticorax nycticorax</i> - Black-crowned night heron							✓	✓
	<i>Plegadis falcinellus</i> - Glossy ibis							✓	
Order:	Falconiformes (Hawks and Falcons)								
	<i>Accipiter striatus</i> - Sharp-skinned hawk								✓
	<i>Circus cyaneus</i> - Marsh hawk					✓		✓	✓
	<i>Falco columbarius</i> - Merlin							✓	✓
	<i>Falco rusticolus</i> - Gyrfalcon							✓	✓
	<i>Falco sparverius</i> - Kestrel							✓	✓
	<i>Pandion haliaetus</i> - Osprey							✓	✓
Order:	Gruiformes (Cranes and Allies)								
	<i>Fulica americana</i> - American coot							✓	✓
	<i>Rallus limicola</i> - Virginia rail							✓	✓
	<i>Rallus longirastus</i> - Clapper rail							✓	✓
Order:	Charadriiformes (Shorebirds, Gulls, and Alcids)								
Family:	Charadriidae (Plovers, Surfbirds)								
	<i>Charadrius melodus</i> - Piping plover							✓	✓
	<i>Charadrius semipalmatus</i> - Semipalmated plover	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Charadrius vociferus</i> - Killdeer	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Charadrius wilsonia</i> - Wilson's plover	✓							✓
	<i>Pluvialis dominica</i> - Golden plover		✓	✓					✓
	<i>Pluvialis squatarola</i> - Black-bellied plover	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Rynchops nigra</i> - Black skimmer							✓	
Family:	Scolopacidae (Sandpipers and Allies)								
	<i>Actitis macularia</i> - Spotted sandpiper	✓	✓		✓		✓	✓	✓
	<i>Arenaria interpres</i> - Ruddy turnstone	✓	✓	✓	✓		✓	✓	✓
	<i>Calidris alba</i> - Sanderling	✓	✓	✓	✓		✓	✓	✓
	<i>Calidris alpina</i> - Dunlin	✓	✓	✓	✓		✓	✓	✓
	<i>Calidris bairdii</i> - Dunlin		✓	✓	✓		✓	✓	✓
	<i>Calidris canutus</i> - Knot						✓	✓	✓
	<i>Calidris fuscicollis</i> - Knot	✓	✓				✓	✓	✓
	<i>Calidris maritima</i> - Purple sandpiper	✓					✓	✓	✓
	<i>Calidris mauri</i> - Western sandpiper						✓	✓	✓
	<i>Calidris melanotos</i> - Pectoral sandpiper						✓	✓	✓
	<i>Calidris minutilla</i> - Least sandpiper				✓		✓	✓	✓
	<i>Calidris pusillus</i> - Semipalmated sandpiper				✓	✓	✓	✓	✓
	<i>Capella gallinago</i> - Common snipe						✓	✓	✓
	<i>Catoptrophorus semipalmatus</i> - Willet							✓	✓
	<i>Limosa fedoa</i> - Marbled godwit								✓
	<i>Limnodromus</i> spp. - Dowitcher	✓	✓	✓			✓	✓	✓
	<i>Limnodromus griseus</i> - Short-billed dowitcher								✓
	<i>Micropalama himantopus</i> - Stilt sandpiper	✓			✓				✓
	<i>Numenius phaeopus</i> - Whimbrel								✓
	<i>Tringa</i> spp. - Yellowlegs	✓	✓	✓	✓	✓	✓	✓	✓
	<i>Tringa solitaria</i> - Solitary sandpiper				✓	✓			✓

Continued

APPENDIX TABLE 12-1. (CONTINUED)

		YEAR	71	72	73	74	75	76	77
Family:	Laridae (Gulls and Terns)								
	<i>Childonia niger</i> - Black tern		/	/	/	/	/	/	/
	<i>Larus argentatus</i> - Herring gull		/	/	/	/	/	/	/
	<i>Larus atricilla</i> - Laughing gull			/	/	/	/	/	/
	<i>Larus delawarensis</i> - Ring-billed gull			/	/	/	/	/	/
	<i>Larus hyperboreus</i> - Glaucous gull			/	/	/	/	/	/
	<i>Larus marinus</i> - Great black-backed gull		/	/	/	/	/	/	/
	<i>Larus philadelphia</i> - Bonaparte's gull		/	/	/	/	/	/	/
	<i>Sterna albifrons</i> - Least tern		/	/	/	/	/	/	/
	<i>Sterna forsteri</i> - Forster's tern		/	/	/	/	/	/	/
	<i>Sterna hirundo</i> - Common tern		/	/	/	/	/	/	/
	<i>Sterna dougallii</i> - Roseate tern							/	
Order:	Columbiformes (Pigeons and Doves)								
	<i>Columba livia</i> - Rock dove		/	/	/	/	/	/	/
	<i>Zenaidura macroura</i> - Mourning dove							/	/
Order:	Passeriformes (Perching Birds)								
	<i>Agelaius phoeniceus</i> - Red-winged blackbird		/		/	/	/	/	/
	<i>Ammodramus caudatus</i> - Sharp-tailed sparrow						/	/	/
	<i>Anthus spinoletta</i> - American pipit						/	/	/
	<i>Carpodacus mexicanus</i> - House finch						/	/	/
	<i>Certhia familiaris</i> - Brown creeper						/	/	/
	<i>Corvus brachyrhynchos</i> - Common crow		/	/	/	/	/	/	/
	<i>Corvus ossifragus</i> - Fish crow		/	/	/	/	/	/	/
	<i>Cyanocitta cristata</i> - Blue jay		/	/			/	/	/
	<i>Dendroica coronata</i> - Myrtle warbler		/	/			/	/	/
	<i>Dendroica dominica</i> - Yellowthroat						/	/	/
	<i>Dendroica palmarum</i> - Palm warbler						/	/	/
	<i>Dolichonyx oryzivorus</i> - Bobolink						/	/	/
	<i>Eremophila alpestris</i> - Horned lark						/	/	/
	<i>Hirundo rustica</i> - Barn swallow		/		/	/	/	/	/
	<i>Iridoprocne bicolor</i> - Tree swallow						/	/	/
	<i>Junco hyemalis</i> - Slate colored junco						/	/	/
	<i>Melospiza melodia</i> - Song sparrow				/		/	/	/
	<i>Mimus polyglottos</i> - Mockingbird						/	/	/
	<i>Molothrus ater</i> - Brown-headed cowbird						/	/	/
	<i>Parus atricapillus</i> - Black-capped chickadee						/	/	/
	<i>Parus bicolor</i> - Tufted titmouse						/	/	/
	<i>Passer domesticus</i> - House sparrow			/	/	/	/	/	/
	<i>Petrochelidon pyrrhonota</i> - Cliff swallow		/		/	/	/	/	/
	<i>Plectrophenax nivalis</i> - Snow bunting		/		/	/	/	/	/
	<i>Quiscalus quiscula</i> - Common grackle					/	/	/	/
	<i>Regulus satrapa</i> - golden-crowned kinglet						/	/	/
	<i>Richmondia cardinalis</i> - Cardinal							/	/
	<i>Riparia riparia</i> - Bank swallow						/	/	/
	<i>Sayornis phoebe</i> - Eastern phoebe						/	/	/
	<i>Spinus tristis</i> - Goldfinch						/	/	/
	<i>Stelgidopteryx ruficollis</i> - Rough-winged swallow		/	/	/	/	/	/	/
	<i>Sturnus vulgaris</i> - Starling		/	/	/	/	/	/	/
	<i>Telmatochlamys palustris</i> - Long-billed marsh wren						/	/	/
	<i>Turdus migratorius</i> - Robin		/	/			/	/	/
	<i>Tyrannus tyrannus</i> - Eastern kingbird		/	/			/	/	/
	<i>Zonotrichia albicollis</i> - White-throated sparrow						/	/	/
Order:	Apodiformes							/	/
	<i>Archilochus colubris</i> - Ruby-throated hummingbird							/	/
Order:	Caprimulgiformes								/
	<i>Chordeiles minor</i> - Nighthawk								/
Order:	Coraciiformes							/	/
	<i>Megasceryle alcyon</i> - Kingfisher			/				/	/
Order:	Piciformes								/
	<i>Colaptes auratus</i> - Common flicker								/

APPENDIX TABLE 12-2. MONTHLY AVERAGE NUMBERS OF REPRESENTATIVE AVIAN SPECIES OBSERVED IN NEW HAVEN HARBOR, 1972 THROUGH 1977. NEW HAVEN HARBOR ECOLOGICAL STUDIES SUMMARY REPORT, 1979.

1972	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Horned grebe	1,379	719	691	1						252	1,566	1,126	1
Black duck		367	3								11	58	5,733
Canvasback	477	6,293	10,520	1,126	35					12	33	1,090	439
Scaup spp.	65	21	39	2							12	110	19,586
Common goldeneye	16	80	5	3	2						7	15	249
Bufflehead									8	14	31		128
Black-bellied plover										87	225	42	53
Dunlin							542	670	4	8	11		354
Sanderling													1,235
Semipalmated sandpiper	2*	1	4		6	59	13	14	10	8	92	15	0
Great black-backed gull	48*	303	109	336	206	150	129	140	373	310	299	67	224
Herring gull	35*		200	300	147	95	60	70	44	33	275	35	2,470
Ring-billed gull	*	2	324	325	77		42	25	34	6			1,294
Bonaparte's gull													728
Common tern													107
TOTAL	2,022	7,786	11,895	2,093	473	304	786	919	473	730	2,562	2,558	32,601

* Does not include 811 of "all 4 types"

Continued

APPENDIX TABLE 12-2. (Continued)

1973	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Horned grebe	2		9	38					342	271	1,293	921	49
Black duck	479	530	165	38	8								4,047
Canvasback	6	100	92						7	380	251	157	198
Scaup spp.	1,765	1,205	2,097	550	2								6,414
Common goldeneye	197	32	159	12							2	45	447
Bufflehead	5	38	25	3							15	9	95
Black-bellied plover					256		9	68	249	23	64		669
Dunlin	11	20			12			75	71	35			224
Sanderling							103	865		18			986
Semipalmated sandpiper							227						227
Great black-backed gull	32	26	9	4		10	1	29	80	11	49		251
Herring gull	76	374	379	122	69	475	531	350	775	35	271	99	3,556
Ring-billed gull	61	410	398	510		183		134	387	60	190	235	2,568
Bonaparte's gull			20	344	2		3	147	240	27	142	145	1,070
Common tern					6	14	74						94
TOTAL	2,634	2,735	3,353	1,621	355	682	948	1,668	2,151	860	2,277	1,611	20,895

Continued

APPENDIX TABLE 12-2. (Continued)

1974	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Horned grebe	1									2			3
Black duck	306	1,498	208	16						359	765	712	3,864
Canvasback		265	45		1								311
Scaup spp.	458	3,285	2,526	1						31	2,778	980	10,059
Common goldeneye	369	120	46	1							5	17	558
Bufflehead	10											10	20
Black-bellied plover					170		1		1	28			200
Dunlin		13			332	9	707	47		25		33	71
Sanderling										80			1,095
Semipalmated sandpiper													80
Great black-backed gull	16	28	11	2	4	3	214	95	151	183	79	51	837
Herring gull	12	109	364	212	5	65	172	661	167	222	62	111	2,162
Ring-billed gull	12	212	183	125	174	15	100	95		51	565	470	2,002
Bonaparte's gull	2	60	695	151	15	18	35	7	5	68		52	1,108
Common tern								182				1	183
TOTAL	1,186	5,590	4,078	508	701	110	1,129	1,087	324	1,049	4,254	2,437	22,553

FAMILY	COMMON NAME	GENUS SPECIES	OCCURRENCE	NAI
Gaviidae	Common loon	<i>Gavia immer</i>	4	✓
	Red-throated loon	<i>Gavia stellata</i>	4	✓
Podicipedidae	Horned grebe	<i>Podiceps auritus</i>	4	✓
	Pied-billed grebe	<i>Podilymbus podiceps</i>	4	✓
Phalacrocoracidae	Great cormorant	<i>Phalacrocorax carbo</i>	4	✓
Anatidae	Mute swan	<i>Cygnus olor</i>	4	✓
	Canada goose	<i>Branta canadensis</i>	4	✓
	Snow goose	<i>Chen hyperborea</i>	4	✓
	Mallard	<i>Anas platyrhynchos</i>	4	✓
	Black duck	<i>Anas rubripes</i>	4	✓
	Pintail	<i>Anas acuta</i>	4	✓
	Gadwall	<i>Anas strepera</i>	4	✓
	Shoveler	<i>Anas clypeata</i>	4	✓
	American wigeon	<i>Anas americana</i>	4	✓
	Greenwinged teal	<i>Anas crecca</i>	4	✓
	Wood duck	<i>Aix sponsa</i>	4	✓
	Red head	<i>Aythya americana</i>	4	✓
	Canvasback	<i>Aythya valisineria</i>	4	✓
	Ringneck duck	<i>Aythya collaris</i>	4	✓
	Greater scaup	<i>Aythya marila</i>	4	✓
	Lesser scaup	<i>Aythya affinis</i>	4	✓
	Common goldeneye	<i>Bucephala clangula</i>	4	✓
	Bufflehead	<i>Bucephala albeola</i>	4	✓
	Oldsquaw	<i>Clangula hyemalis</i>	4	✓
	King eider	<i>Somateria spectabilis</i>	2	✓
	White-winged scoter	<i>Melanitta deglandi</i>	4	✓
	Black scoter	<i>Melanitta nigra</i>	4	✓
	Ruddy duck	<i>Oxyura jamaicensis</i>	4	✓
	Common merganser	<i>Mergus merganser</i>	4	✓
	Hooded merganser	<i>Lophodytes cucullatus</i>	4	✓
	Red-breasted merganser	<i>Mergus serrator</i>	4	✓

APPENDIX TABLE 12-3. (Continued)

FAMILY	COMMON NAME	GENUS SPECIES	OCCURRENCE	NAI
Accipitridae	Goshawk	<i>Accipiter gentilis</i>	4	✓
	Coopers hawk	<i>Accipiter cooperii</i>	4	✓
	Sharp-shinned hawk	<i>Accipiter striatus</i>	2,4	✓
	Marsh hawk	<i>Circus cyaneus</i>	4	✓
	Red-tailed hawk	<i>Buteo jamaicensis</i>	4	✓
	Rough-legged hawk	<i>Buteo lagopus</i>	4	✓
	Red-shouldered hawk	<i>Buteo lineatus</i>	4	✓
	Golden eagle	<i>Aquila chrysaetos</i>	4	✓
	Bald eagle	<i>Haliaeetus leucocephalus</i>	4	✓
	Osprey	<i>Pandion haliaetus</i>	4	✓
Falconidae	Gyr Falcon	<i>Falco rusticolus</i>	3	✓
	American kestrel	<i>Falco sparverius</i>	4	✓
Tetraonidae	Ruffed grouse	<i>Bonasa umbellus</i>	4	✓
Phasianidae	Bobwhite	<i>Colinus virginianus</i>	4	✓
	Ring-neck pheasant	<i>Phasianus colchicus</i>	4	✓
Ardeidae	American bittern	<i>Botaurus lentiginosus</i>	4	✓
	Great blue heron	<i>Ardea herodias</i>	4	✓
	Black-crowned night heron	<i>Nycticorax nycticorax</i>	4	✓
	Louisiana heron	<i>Hydranassa tricolor</i>	1	✓
Rallidae	Virginia rail	<i>Rallus limicola</i>	4	✓
	Sora	<i>Porzana carolina</i>	4	✓
	King rail	<i>Rallus elegans</i>	4	✓
	Clapper rail	<i>Rallus longirostris</i>	4	✓
	American coot	<i>Fulica americana</i>	4	✓
Charadriidae	Killdeer	<i>Charadrius vociferus</i>	4	✓

(Continued)

FAMILY	COMMON NAME	GENUS SPECIES	OCCURRENCE	NAI
Scolopocidae	Purple sandpiper	<i>Calidris maritima</i>	4	✓
	Ruddy turnstone	<i>Arenaria interpres</i>	4	✓
	Dunlin	<i>Calidris alpina</i>	4	✓
	American woodcock	<i>Philohela minor</i>	4	✓
	Common snipe	<i>Capella gallinago</i>	4	✓
Laridae	Glaucous gull	<i>Larus hyperboreus</i>	4	✓
	Iceland gull	<i>Larus glaucooides</i>	4	✓
	Great black-backed gull	<i>Larus marinus</i>	4	✓
	Herring gull	<i>Larus argentatus</i>	4	✓
	Ring-billed gull	<i>Larus delewarensis</i>	4	✓
	Laughing gull	<i>Larus atricilla</i>	4	✓
	Bonaparte's gull	<i>Larus philadelphia</i>	4	✓
	Black-headed gull	<i>Larus ridibundus</i>	1	✓
				12-51
Columbidae	Rock dove	<i>Columba livia</i>	4	✓
	Mourning dove	<i>Zenaidura macroura</i>	4	✓
Tytonidae	Barn owl	<i>Tyto alba</i>	4	✓
Strigidae	Great-horned owl	<i>Bubo virginianus</i>	4	✓
	Long-eared owl	<i>Asio otus</i>	4	✓
	Short-eared owl	<i>Asio flammeus</i>	4	✓
	Screech owl	<i>Otus asio</i>	4	✓
	Barred owl	<i>Strix varia</i>	4	✓
Alcedinidae	Belted kingfisher	<i>Megaceryle alcyon</i>	4	✓
Picidae	Common flicker	<i>Colaptes auratus</i>	4	✓
	Red-headed woodpecker	<i>Melanerpes erythrocephalus</i>	4	✓
	Yellow-bellied sapsucker	<i>Sphyrapicus varius</i>	4	✓
	Hairy woodpecker	<i>Dendrocopos villosus</i>	4	✓
	Downy woodpecker	<i>Dendrocopos pubescens</i>	4	✓
	Red-bellied woodpecker	<i>Centurus carolinus</i>	1, 4	✓
Tyrannidae	Eastern phoebe	<i>Sayornis phoebe</i>	4	✓

Continued

APPENDIX TABLE 12-3. (Continued)

FAMILY NAME	COMMON NAME	GENUS SPECIES	OCCURRENCE	NAI
Alaudidae	Horned lark	<i>Eremophila alpestris</i>	4	✓
Corvidae	Blue jay	<i>Cyanocitta cristata</i>	4	✓
	Common crow	<i>Corvus brachyrhynchos</i>	4	✓
	Fish crow	<i>Corvus ossifragus</i>	1,4	✓
Paridae	Black-capped chickadee	<i>Parus atricapillus</i>	2,4	✓
	Boreal chickadee	<i>Parus hudsonicus</i>	4	✓
	Tufted titmouse	<i>Parus bicolor</i>	4	✓
Sittidae	White-breasted nuthatch	<i>Sitta carolinensis</i>	4	✓
	Redbreasted nuthatch	<i>Sitta canadensis</i>	4	✓
Certhiidae	Brown creeper	<i>Certhia familiaris</i>	4	✓
Troglodytidae	House wren	<i>Troglodytes aedon</i>	4	✓
	Winter wren	<i>Troglodytes troglodytes</i>	4	✓
	Carolina wren	<i>Thryothorus ludovicianus</i>	4	✓
	Longbilled marsh wren	<i>Telmatodytes palustris</i>	4	✓
Mimidae	Mockingbird	<i>Mimus polyglottos</i>	4	✓
	Catbird	<i>Dumetella carolinensis</i>	4	✓
	Brown thrasher	<i>Toxotoma rufum</i>	4	✓
Turdidae	Robin	<i>Turdus migratorius</i>	4	✓
	Hermit thrush	<i>Catharus guttata</i>	4	✓
	Swainson thrush	<i>Catharus ustulata</i>	4	✓
	Eastern bluebird	<i>Sialia sialis</i>	4	✓
Sylviidae	Golden crowned kinglet	<i>Regulus satrapa</i>	4	✓
	Ruby crowned kinglet	<i>Regulus calendula</i>	4	✓
Motacillidae	Water pipit	<i>Anthus spinoletta</i>	4	✓
Bombycillidae	Cedar waxwing	<i>Bombycilla cedrorum</i>	4	✓

(Continued)

FAMILY	COMMON NAME	GENUS SPECIES	OCCURRENCE	NAI
Laniidae	Northern shrike	<i>Lanius excubitor</i>	4	✓
	Loggerhead shrike	<i>Lanius ludovicianus</i>	4	✓
Sturnidae	Starling	<i>Sternus vulgaris</i>	4	✓
Parulidae	Yellow-rumped warbler	<i>Dendroica coronata</i>	4	✓
	Hermit warbler	<i>Dendroica occidentalis</i>	1	✓
	Cerulean warbler	<i>Dendroica cerulea</i>	1	✓
	Yellow throat	<i>Geothlypis trichas</i>	4	✓
	Yellow-breasted chat	<i>Icteria virens</i>	4	✓
Ploceidae	House sparrow	<i>Passer domesticus</i>	4	✓
Icteridae	Eastern meadowlark	<i>Sturnella magna</i>	4	✓
	Red-winged blackbird	<i>Agelaius phoeniceus</i>	4	✓
	Rusty blackbird	<i>Euphagus carolinus</i>	4	✓
	Grackle	<i>Quiscalus quiscula</i>	4	✓
	Brown-headed cowbird	<i>Molothrus ater</i>	4	✓
	Northern oriole	<i>Icterus galbula</i>	4	✓
Fringillidae	Cardinal	<i>Richmondia cardinalis</i>	4	✓
	Evening grosbeak	<i>Hesperiphona vespertina</i>	4	✓
	Purple finch	<i>Carpodacus purpureus</i>	4	✓
	House finch	<i>Carpodacus mexicanus</i>	4	✓
	Pine siskin	<i>Spinus pinus</i>	4	✓
	American goldfinch	<i>Spinus tristis</i>	4	✓
	Red crossbill	<i>Loxia curvirostra</i>	4	✓
	Dickcissel	<i>Spiza americana</i>	4	✓
	Rufous sided towhee	<i>Pipilo erythrophthalmus</i>	4	✓
	Savannah sparrow	<i>Passerculus sandwichensis</i>	4	✓
	Henslow sparrow	<i>Ammodramus henslowii</i>	2	✓
	Sharp-tailed sparrow	<i>Ammodramus caudatus</i>	4	✓
	Seaside sparrow	<i>Ammodramus maritima</i>	4	✓
	Vesper sparrow	<i>Poocetes gramineus</i>	4	✓

(Continued)

APPENDIX TABLE 12-3. (Continued)

FAMILY	COMMON NAME	GENUS SPECIES	OCCURRENCE	NAI
Fringillidae (Continued)	Slate-colored junco	<i>Junco hyemalis</i>	4	✓
	Tree sparrow	<i>Spizella arborea</i>	4	✓
	Field sparrow	<i>Spizella pusilla</i>	4	✓
	White-crowned sparrow	<i>Zonotrichia leucophrys</i>	4	✓
	Song sparrow	<i>Melospiza melodia</i>	4	✓
	Swamp sparrow	<i>Melospiza georgiana</i>	4	✓
	Fox sparrow	<i>Passerella iliaca</i>	4	✓
	White-throated sparrow	<i>Zonotrichia albicollis</i>	4	✓
	Lapland longspur	<i>Calcarius lapponicus</i>	4	✓
	Snow bunting	<i>Calcorius pictus</i>	4	✓

12-54

KEY:

- 1 = Spring migration, April 1 - May 30
- 2 = Fall migration, August 1 - November 30
- 3 = Winter, December 1 - February 28
- 4 = Christmas count, December 18 - January 2

NEW HAVEN HARBOR
ECOLOGICAL STUDIES
SUMMARY REPORT, 1979

13.0 SUMMARY

TABLE OF CONTENTS

	PAGE
<i>HYDROGRAPHY AND WATER QUALITY.</i>	13-2
<i>Impact</i>	13-3
<i>PLANKTON</i>	13-4
<i>Phytoplankton.</i>	13-5
<i>Zooplankton.</i>	13-6
<i>Ichthyoplankton.</i>	13-7
<i>Impact</i>	13-8
<i>BENTHIC STUDIES.</i>	13-9
<i>EXPOSURE PANELS.</i>	13-10
<i>Impacts.</i>	13-11
<i>SUBTIDAL BENTHOS</i>	13-12
<i>Impacts.</i>	13-13
<i>INTERTIDAL INFAUNA</i>	13-14
<i>Impacts.</i>	13-15
<i>EPIBENTHIC INVERTEBRATES</i>	13-16
<i>Impacts.</i>	13-17
<i>OYSTER STUDY</i>	13-17
<i>TRACE METALS</i>	13-19
<i>Impacts.</i>	13-19
<i>FINFISH.</i>	13-20
<i>Impacts.</i>	13-21
<i>AVIFAUNA</i>	13-23
<i>Impacts.</i>	13-24
<i>SUMMATION.</i>	13-25

13.0 SUMMARY

New Haven Harbor Ecological Studies were undertaken from 1970 through 1977 as part of requirements for siting, design, construction and operation of the New Haven Harbor Station. Because this effort was coincident with several pieces of major environmental legislation and was responsive to several different state and federal agencies, there is no single regulation or permit which fully describes the basis for the study. Studies were conducted to evaluate potential environmental impacts, to aid development of recommendations for mitigative design measures and to monitor environmental effects of construction and operation of the facility.

During planning and construction phases, the U.S. Army Corps of Engineers (ACE) was the lead federal agency and in 1972 prepared an Environmental Impact Statement. Construction permits were granted and in October 1973 an NPDES permit was issued by the Connecticut DEP authorizing operation of the facility through June 1977 and specifying monitoring and reporting requirements. The subsequent NPDES permit, effective June 30, 1977 included a requirement for ...

"a summary report concerning all biological monitoring studies. Such a report shall address the relationship of monitoring data collected after station start-up to baseline data collected prior to station operation."

The New Haven Harbor Ecological Studies Summary Report, prepared in response to this requirement, presents the results of 1970-1977 studies with emphasis on the preoperational monitoring studies for 1973 (when the discharge permit was issued) through August 1975 (when the plant began commercial operations), and on operational phase studies from September 1975 through October 1977. In addition to the required objective of identifying and evaluating possible impacts of the generating station on the harbor ecosystem, this report was organized to

maximize the utility of the data to other investigators by presenting, independent of plant impact considerations, and for each component of the program, a summary of study findings.

The study program addressed harbor hydrography and the plant's thermal plume as well as the following biological components: phyto-, zoo- and ichthyoplankton, subtidal and intertidal benthos, fouling organisms, epibenthic invertebrates, oyster growth, trace metals in organisms and sediments, finfish and birds. Mechanisms of potential impacts of the 460-MW oil-fired generating station are almost entirely related to operation of its $18 \text{ m}^3/\text{s}$ (625 cfs) cooling system which adds waste heat to the harbor at a rate of 545 Kgal/hr (2×10^9 Btu/hour) at a design temperature increase of 8.3°C (15°F).

A synopsis of the results of each program is presented below in a formal paralleling that of the corresponding papers; most provide a summary of characterization followed by a summary of plant impact evaluations.

HYDROGRAPHY AND WATER QUALITY

Water circulation in New Haven Harbor is largely controlled by tidal forces, geomorphological features, and freshwater runoff. Over 40% of the harbor volume is moved in and out with each tidal cycle (tidal prism). Tidal currents are strongest (averaging approximately 30 cm/sec [1 ft/sec]) in the deeper parts of the harbor, particularly in the ship channel (Figure 1a) which is approximately 10 m (33 ft) deep. Shoal areas are more extensive on the western than on the eastern side of the harbor; consequently, tidal flushing tends to be more efficient on the eastern side. Strong vertical stratification occurs only during periods of high freshwater runoff when a net seaward flow of surface water sets up a return flow from Long Island Sound along the bottom.

The inner harbor (1600 acres, bounded on the north by the confluence of the Mill and Quinnipiac Rivers, and on the south by a line from Sandy Point to Fort Hale) experiences greater environmental stress due to direct discharges of municipal and industrial wastes than the outer harbor (5500 acres, bounded by inner harbor, and Long Island Sound breakwaters). Inner harbor waters also characterized by natural high thermal, salinity, and river sediment load fluctuations.

Impact

Condenser cooling water for the New Haven Harbor Station is withdrawn from the harbor via a dredged intake channel which extends from the main ship channel approximately 270 m (886 ft) to the eastern shore (Figure 13-1). Water currents at the western end of the intake channel are deflected less than 20° eastward from their essentially north-south orientation by this withdrawal. An intake incurrent of not more than 25 cm/sec (0.8 fps) rapidly diminishes to less than 10 cm/sec (0.3 fps) a few meters out from the intake structure.

Heated cooling water is discharged horizontally through a single diffuser port approximately 210 m (700 ft) from shore and 11 m (35 ft) below mean low water. Discharge water velocity, up to 300 cm/sec (10 fps), creates maximum currents of no more than 90 cm/sec (3 fps) near the easterly edge of the ship channel. Added heat is usually sufficient to cause the discharge plume to rise to the surface. Only occasionally, during late winter and early spring periods of high runoff has a submerged plume been observed. Although under a certain combination of wind and tide it may be possible that the plume might briefly contact the eastern shore, there has been no evidence to date of any such occurrences.

Aerial infrared radiometry and three-dimensional thermal and dye studies have shown a maximum temperature rise (ΔT) in surface waters of about 2.8°C (5°F) above ambient. The percentage of the surface area

of the inner harbor bounded by the 4°F (2.2°C) ΔT isotherm was less than 0.1%. The 3, 2 and 1°F (1.7, 1.1 and 0.6°C) ΔT isotherms bound 0.4, 0.6 and 1 percent respectively of the inner harbor surface area (NAI, 1976). Numerical model results indicate that operation of New Haven Harbor Station raises the average water temperature of the inner harbor by 0.4°C (0.7°F), and that of outer harbor by 0.3°C (0.5°F).

PLANKTON

The protection against dispersal afforded by inlets and western shoal areas in New Haven Harbor combined with nutrient input from municipal sewage provide a fertile habitat for phytoplankton populations. Harbor waters also support substantial zooplankton and ichthyoplankton populations which ultimately depend on phytoplankton primary production for sustenance. Most finfish and many benthic invertebrates, such as crabs and oysters, spend a portion of their lives in the plankton. Thus, any change in planktonic populations affects, not only the food available to subsequent levels in the food web, but also the magnitude of larval recruitment to adult populations of many aquatic animals.

Of the two potential sources of power plant impact on the plankton community, i.e., entrainment in the power plant's cooling system, and exposure to the heated discharge as it diffuses and mixes with the receiving water, power plant passage has in general been considered to pose the more serious problem (Miller and Beck, 1975). Recent studies have indicated substantial survival of planktonic organisms after power plant passage, when temperatures were below thermal threshold levels (ca. 30°C for many species). The 100% mortality level is utilized as a worst-case analysis, because additional deaths may be delayed until long after completion of transit through the cooling system.

Although susceptible to the same thermal and mechanical stresses as zooplankters, phytoplankters possess enormously greater reproductive potential (often doubling population size in less than a day) and thus can more easily accommodate extremely high individual cell attrition rates. High cell attrition rates occur naturally by the cells sinking and by herbivorous zooplankton grazing pressures. Although there is no reason to consider individual phytoplankton cell deaths a significant issue with regard to power plant impact, changes in overall levels of production and standing stock and/or a shift in the kinds of phytoplankton produced in the altered system are potentially real and important considerations (Yentsch, 1977).

Phytoplankton

Studies of New Haven Harbor phytoplankton were based on monthly surface water bottle samples and included estimates of standing crop as well as identification and enumeration of phytoplankton taxa. Standing crop, measured as chlorophyll a concentrations, generally remained at low levels from September through January and was somewhat higher from February through August. There was considerable variability in monthly values, probably due to differences in timing and magnitude of phytoplankton blooms, which cannot be fully characterized by once-monthly sampling. From 1971 through 1975, major chlorophyll a peaks occurred in spring, summer and/or fall. During 1976 and 1977, the frequency of occurrence and magnitude of major chlorophyll a peaks increased and, unlike previous years, major peaks were also observed during late winter (February/March) throughout New Haven Harbor.

In correspondence with chlorophyll trends, total phytoplankton cell densities tended to increase over the period from 1974 through 1977. During 1974 and 1975, peak densities generally coincided with peak water temperatures and day length, during July - August. In 1976 there was a large peak in February: in the outer harbor, a decline to a June minimum was followed by a second peak in August, while in the inner harbor the spring/summer peaks were more sporadic. In 1977 the February

peak reoccurred, and was followed by June and August peaks. Additional localized pulses occurred during April and October. Common Long Island Sound diatoms, *Skeletonema costatum* and *Thalassiosira/Cyclotella* species, and microflagellates were among the ten dominant taxa during every month, while more seasonal contributions to community dominance were made by other taxa including nontoxic dinoflagellates (generally late spring and summer).

Zooplankton

Zooplankton populations were studied by a program of monthly sampling using towed nets. From 1973 through 1976, total zooplankton abundances in New Haven Harbor were usually at lowest seasonal levels in December and January. Abundances generally increased to seasonal peaks by March or April, remained at peak levels with some fluctuations through June, and declined by July or August.

Early spring zooplankton-density increases reflected the appearance of larval stages of calanoid copepod species (particularly *Acartia hudsonica*) and barnacles. Late spring and early summer was a period of particularly intense reproductive activity for many benthic invertebrates including barnacles, polychaetes, bivalves and gastropods. Production of planktonic larvae continued throughout the summer with peak abundances during the warmest months of the year (July and August). *Acartia tonsa* was an important mid- to late summer dominant. In autumn, a winter faunal assemblage, consisting of calanoid copepods and barnacle larvae, returned to prominence.

Copepods were the most abundant planktonic group in New Haven Harbor. *Acartia tonsa* and *Acartia hudsonica* (= *clausi*), the dominant copepods, together comprised up to 93% of the total copepod assemblage. *A. hudsonica* normally reached peak densities in the spring and was succeeded by *A. tonsa* populations during mid- to late summer. Other abundant calanoid copepods, all common to Long Island Sound, were

characterized by substantial seasonal abundance peaks. Early copepod developmental stages (i.e., nauplii and copepodites) have been seasonally important and during time of high abundance are numerically dominant. Though relatively scarce in 1977 collections, cyclopoid copepods of the genus *Oithona* have occurred in New Haven Harbor on a fairly regular and essentially year-round basis.

Ichthyoplankton

More than 45 ichthyoplankton taxa were identified in New Haven Harbor from 1974 through 1977, with a distribution among dominant taxa similar to those reported for Long Island Sound and adjacent waters from various studies between 1943 and 1975. Anchovy and cunner eggs, and anchovy and sand lance larvae were numerical dominants, while fourbeard rockling (possibly mixed with hake) eggs were also important. Though New Haven Harbor may be an important nursery area for weakfish and winter flounder, neither eggs nor larvae of these fish were abundant in the ichthyoplankton.

During each year from 1974 through 1977, total fish egg abundance generally peaked during June and July -- anchovy eggs were dominant. During the remainder of the year, fish egg abundances were relatively low. Fish-egg densities were generally higher at outer harbor stations except during 1977, when fish eggs were more abundant at mid-harbor, channel stations. Dominant taxa were cunner (1974-1976), anchovies (1976, 1977) and mackerel (1977). Seasonal abundance patterns of the dominant taxa did not vary much over the four-year study period and, the inter-year variation of dominants that was observed was consistent over all stations.

Larval fish were most abundant during July and August when anchovies predominated. In addition to anchovies, sand lance (February-April) and winter flounder (April-May) larvae, though present only in low densities, were seasonal dominants. Overall, fish larval densities were highest for most years just outside the breakwaters and were lowest near the West River entrance.

Impact

As evidenced by chlorophyll a values, phytoplankton blooms have not been reduced but have progressively increased in magnitude during the post-operational years (1975 through 1977). Due to natural variability in phytoplankton standing stock and its dependence on many factors, it is difficult to isolate causes of long-term changes in production levels; such assessment is particularly difficult in nutrient-enriched areas (such as New Haven Harbor) where standing stock varies considerably among years (Flemer and Sherk, 1977).

Differences observed in zooplankton assemblages were assessed by evaluating whether operational data fell within the ranges established by preoperational monitoring. With the change in sampling methodologies, these comparisons were made qualitatively, based on a conversion between methods, and indicated that no substantial or important change in zooplankton density or distribution patterns can be attributed to New Haven Harbor Station operation.

Dominant taxonomic groups of ichthyoplankton collected in New Haven Harbor were similar from year to year. Observed seasons of peak occurrence, dominant taxa and species represented among the ichthyoplankton in New Haven Harbor all closely resembled comparable data collected and reported by previous investigators of Long Island Sound ichthyofauna. Year-to-year fluctuations in total ichthyoplankton abundance, as well as abundance of selected taxa, are comparable to the natural variability seen in studies conducted in Long Island Sound and vicinity between 1943 and 1968.

Overall, New Haven Harbor plankton assemblages observed subsequent to operation of New Haven Harbor Station are indistinguishable, qualitatively and quantitatively, from those observed prior to power plant operation. A notable exception was a general increase in phytoplankton standing crop. It is beyond the scope of this investigation to determine specific causes, but the increase may be related to such influ-

ences as improved water quality (undocumented) and expanded treatment of municipal water discharges.

BENTHIC STUDIES

Organisms living on or in bottom substrates in New Haven Harbor occupy intertidal and subtidal muds and sands as well as wood, rock and concrete structures including pilings, old barges, bulkheads and jetties. These benthic assemblages are relatively stationary and to survive must withstand all extremes in physical and chemical parameters that occur in the water column. In this regard, the benthos are unlike plankton, which move with water currents, and unlike pelagic and demersal finfish and large motile epibenthic invertebrates, which may move about in response to physical and chemical parameters. Thus the characteristics of the benthos at a given place and time should reflect the cumulative conditions prior to that time. Plankton, finfish and mobile epibenthic organisms at a given point in time give less indication of what conditions may have been on the preceding day or weeks. Studies included in this report which directly address components of the benthos are (5) Exposure Panels, (6) Subtidal Infauna and (7) Intertidal Infauna. Larger, motile invertebrates are considered in (8) Epibenthic Invertebrates. Oyster growth and mortality are addressed in (9) Oyster Study. A special study examining accumulation of trace metals by benthic organisms is included in (10) Trace Metal Studies, which also takes a much broader view of trace metal processes in general and throughout Long Island Sound.

Power generating stations utilizing once-through cooling systems impact the marine benthic environment in a number of ways. The direct impact of the heated effluent may be sufficient to elevate temperatures in the receiving body of water to a point which is detrimental to the survival of some of the resident species, particularly those that are near their tolerance limits for temperature or other physical factors. This type of impact may affect adults, juveniles, or larvae of benthic infauna. Further, heat may alter competitive advantages or behavior, indirectly producing mortality. Added heat may alter

metabolic rates, feeding activities, length of spawning or settlement periods or various behavioral characteristics. Reflected changes in benthic assemblages could include modified productivity, changed densities, addition or elimination of species, or more subtle shifts in species composition. Although the direct effects of heat on marine communities have received considerable attention from the public, they have been shown in many cases to be one of the least objectionable impacts of generating stations. In New Haven Harbor the low ratio of plant cooling water flow to the volume of water moved with each tide, the minimal harbor area experiencing heightened temperatures from the discharge plume, and the lack of direct plume contact with the benthic habitat, minimizes potential impact of plant operations on the benthos.

Entrainment of planktonic larvae through station cooling systems often produces large mortalities (Enright, 1977). Most of the dominant benthic species in New Haven Harbor have planktonic larvae and are therefore potentially subjected to losses from this impact. The net effect of this impact is best inferred from recruitment patterns during appropriate seasons. Another type of impact, impingement on the intake screens may often be severe for populations of finfish and megabenthic invertebrates (large, motile forms such as lobsters and crabs). Infaunal benthic invertebrate species are generally not subject to impingement losses.

EXPOSURE PANELS

Seventy-five species and numerous higher taxa representative of general hard-substrate benthic communities were identified from New Haven Harbor exposure panels during the study. The long-term fouling community was dominated by barnacles (*Balanus* spp.), hydroids (*Obelia longissima*), mussels (*Mytilus edulis*), marine borers (*Teredo navalis*), mudworms (*Polydora ligni*) and tube-dwelling amphipods (*Corophium insidiosum*). All dominants were consistently collected except *Teredo navalis*, which disappeared from the harbor from 1976 through the study period, but has been observed in July 1978 samples. Most taxa exhibited seasonal fluctuations in abundance related to spawning and settlement. Long-term

panels did not show clear species-richness seasonal patterns. In some years, high summer species-richness values on long-term panels occurred (1977), but spring or fall maxima were equally prevalent over the entire seven-year study period. The number of taxa was usually lower at Long Wharf (inner harbor) than Harbor Station or Fort Hale (outer harbor). Though species richness on long-term panels showed annual increases from 1971 through 1976 and a decrease in 1977, the changes appear to reflect taxonomic refinements, panel losses and length of sampling period, rather than any real change in species richness.

Short-term fouling panel dominants were similar to those on long-term panels. Most species settled from June through October during and after the reproductive season, with maximum species-richness values in July, August and September for all years. As with long-term panels, an increase in short-term panel species-richness values from 1971 through 1977 was probably a result of taxonomic refinements, but could also be indicative of some water quality improvements as was the case with species diversity at Niantic Bay (Battelle, 1978). For most years, settlement on short-term panels was greater at New Haven Harbor Station and Fort Hale than Long Wharf, probably reflecting deteriorated water quality at Long Wharf.

Impacts

Species composition, distribution and abundances of fouling community members remained relatively consistent in New Haven Harbor throughout the study period. None of the dominant species showed changes in distribution or abundance that could be related to station operation. Both because its disappearance was not localized at Harbor Station and because it has been recorded in high numbers in recent (1978) data, *Teredo's* absence from 1976 to 1978 is not considered to be related to New Haven Harbor Station operation. Fluctuation in seasonal and annual distributions of panel-community members in New Haven Harbor is characteristic of the assemblage; similar patterns have been seen in

other fouling-panel studies in the greater Long Island Sound area. The harbor in general appears to support a productive and relatively stable panel community which has not been impacted by the New Haven Harbor Station operation.

SUBTIDAL BENTHOS

Species inventories generated by the benthic studies conducted under the supervision of Normandeau Associates, Inc. (NAI) from 1973-1977 and by Rhoads and Michael (R&M) from 1974-1978 were combined, and the resulting species list comprised over 300 taxa. Many of these were recognized as occurring only as juvenile or immature specimens or being present so rarely that they were not characteristic of the New Haven Harbor benthos. Fourteen ubiquitous or dominant species were identified as "characteristic" of the New Haven Harbor benthos. These included five polychaetes (*Glycera americana*, *Nephtys incisa*, *Nereis succinea*, *Polydora ligni* and *Streblospio benedicti*), oligochaetes, four bivalves (*Gemma gemma*, *Tellina agilis*, *Nucula proxima* and *Mulinia lateralis*), mud snails (*Nassarius trivittatus*), mysids (*Neomysis americana*), sand shrimp (*Crangon*) and hermit crabs (*Pagurus longicarpus*).

An examination of spatial and temporal patterns of species richness revealed that most stations supported few species at any time and that no recognizable seasonal patterns were evident. Species richness and diversity at the Morris Cove control stations were found to be consistently greater than at inner harbor stations. An "August effect", characterized by heightened summer infaunal mortalities concurrent with maximum temperatures and minimal dissolved oxygen levels, was hypothesized in previous (R&M) annual reports. When the combined data sets were considered, summer declines in density and species richness, though still evident, were somewhat less pronounced.

Faunal density was spatially and temporally quite variable, a situation typical of benthic assemblages in highly stressed environ-

ments where achievement of a dynamic equilibrium is prevented by rapid and unpredictable environmental changes. Faunal density was marked by annual summer minima and fall recovery with the result that most dense populations were recorded in late fall/early winter. The "August effect" of reduced summer density appears to be associated with three combined factors of sufficient depth to allow dissolved oxygen diminution at the bottom, an organic-rich silt-clay substratum, and location in the inner harbor. This combination of factors, in conjunction with the other environmental stresses in the harbor, appear to be responsible for mass mortalities during peak stress periods in August.

Numerical classification analyses identified four station clusters in the harbor; two resembled community types that have been identified from other east coast estuaries. Stations in the inner harbor, due to their more variable fauna, did not cluster well, and only one group of three similar stations was identified. Two sediment-controlled community types were recognized from the Morris Cove samples.

The combined data sets show New Haven inner harbor to be a highly-stressed area characterized by variable and unpredictable biological parameters. The various pollutant sources in and around the harbor combine to severely limit standing stocks of benthic macrofauna, as reflected by low diversity values. The impacts associated with the inner harbor appear to decrease with increasing distance from their source as shown by the similarities noted between the fauna of Morris Cove and that of Clinton Harbor, a relatively pristine Long Island Sound estuary.

Impacts

No significant differences in subtidal benthic species richness or faunal density were observed between preoperational and operational years. Morris Cove contained more species in greater abundance than the inner harbor during both preoperational and operational periods.

Analysis of changes in abundances of the fourteen characteristic species indicated that nine species showed significant increases in abundance over the period of the study, and no species decreased in abundance.

Similar statistical tests on the diversity values indicate that no statistically significant changes in diversity were found over the course of the program. All of the data-analysis results indicate that there has been no significant change in the structure of the benthic infaunal communities of New Haven Harbor due to the operation of New Haven Harbor Station.

INTERTIDAL INFAUNA

Spring and fall sampling along three transects were utilized to monitor the intertidal habitat (over 600 acres) in New Haven Harbor. During seven years of sampling, a total of 90 invertebrate taxa were collected. Soft-shell clams (*Mya arenaria*), sandworms (*Nereis succinea*), gem clams (*Gemma gemma*), mudsnails (*Ilyanassa obsoleta*), macoma clams (*Macoma balthica*), barnacles (*Balanus improvisus*), spionid worms (Spionidae), horseshoe crabs (*Limulus polyphemus*) and capitellid worms (Capitellidae) were commonly collected, although individual and total organism densities varied substantially from year to year. Except for horseshoe crabs, mud snails and some polychaete worms, most of the abundant taxa are sessile infaunal organisms that settle predominantly in the summer. Overall density variation was most pronounced at East Shore and Long Wharf, reflecting large fluctuations in soft-shell clam density. Species richness was also highly variable and showed no annual trends. Seasonal patterns in richness and organism densities were both usually greater in fall than spring, due to spring and summer recruitment and winter mortalities. Of the three stations sampled, Sandy Point had the greatest numbers of species and organism densities, while East Shore usually was lowest for both parameters.

Impacts

A qualitative comparison of mean numbers of taxa indicated that species richness did not change substantially in the operational period. A similar comparison of total numbers of organisms indicated an operational decrease at Long Wharf which was attributable to a large natural variation in *Mya* densities. Dominant fauna collected in pre-operational samples were generally found at similar or increased densities after plant operation had begun. Only *Gemma gemma* showed a population change coincident with plant operation. A decline in population density of *Gemma* at Sandy Point in May 1975 just prior to commencement of operations in addition to a decline at Long Wharf in October 1975, may indicate a harborwide decrease in *Gemma* populations rather than a localized decrease related to station operation.

Analysis of change by sampling period showed considerable variability. Declines in species richness and densities were detected in October 1976 samples at the inner harbor stations, Long Wharf and East Shore, and were probably related to low levels of dissolved oxygen. October reductions in species richness and organism density were not observed in 1977, indicating that the die-off observed in 1976 was not a regular summer phenomenon in New Haven Harbor.

None of the fluctuations in distribution and abundance in New Haven Harbor were suggestive of operational impact of New Haven Harbor Station on intertidal assemblages. The dominant taxa collected in the intertidal zone are opportunistic species which characteristically utilize an unpredictable environment by virtue of their ability to increase in density rapidly and to exist in dense populations. Unless new severe stresses occur in the Harbor, it appears that intertidal areas will continue to offer the same resources to tolerant colonists and subsequent foragers and predators with little or no consequence from operation of the New Haven Harbor Station.

EPIBENTHIC INVERTEBRATES

During the course of the New Haven Harbor Station Ecological Monitoring Studies, 44 epibenthic invertebrate taxa were collected. In general, abundance was highest during periods of moderate water temperatures, from late spring to early summer and fall; it was lowest during periods of extreme water temperature, during winter and, more notably, mid-summer. Seasonal abundance patterns may have reflected local inshore-offshore movements or changing degrees of organism activity and thus exposure to capture by sampling gear.

The most abundant trawl organisms were sand shrimp (*Crangon septemspinus*), common starfish (*Asterias forbesi*), rock crabs (*Cancer irroratus*), lady crabs (*Ovalipes ocellatus*) and mantis shrimp (*Squilla empusa*). Sand shrimp comprised from over 50 to 90% of the total annual catch. Densities were highly variable but tended to be lowest at outer harbor stations and generally lower in the harbor during summer months. Starfish annual abundances declined steadily at all stations during the monitoring program with no seasonal or spatial trends evident. Rock crab and lady crab annual abundances varied widely, and both crabs had distinct seasonal abundance patterns. Rock crabs were well-represented during all seasons except summer. For lady crabs, annual abundance differences were particularly high, with total number captured ranging from 60 individuals in 1974 to 3200 in 1977. Largest numbers were consistently collected during late summer and early fall in the inner harbor and Morris Cove. The deep-burrowing stomatopod shrimp, *Squilla*, was captured almost exclusively in fall trawls in channel stations. Lobsters (*Homarus americanus*) are the only commercially important trawl invertebrates in New Haven Harbor and comprised about 1% of the trawl catch in each year of the sampling program. Lobster abundances peaked regularly in spring and, occasionally, in the fall. Summer and winter lobster catch was characteristically low. Catch was highest in the channel near the Harbor Station discharge throughout the program and lowest in the shallow inner harbor and outer harbor areas.

Impacts

An evaluation of the total impact of the Harbor Station on the epibenthic community was made by comparison of annual and monthly trends in species composition, abundance and distribution prior to and during operation of the New Haven Harbor Station. The total number of epibenthic species collected annually was similar for each year of the study. The only species that showed any major consistent change in annual abundance was the starfish, *Asterias forbesi*, which decreased consistently from 1974 to 1977. The observed decline in the catch abundance of starfish was probably due to either "mopping" and the use of biocides such as lime (calcium oxide) by commercial oyster companies to protect oyster beds from starfish predation, or simply long-term starfish abundance fluctuations, which are common and well documented in Long Island Sound (Galtsoff, 1969), rather than to construction or operation of the Harbor Station.

For all other species, variations observed in species composition, distribution and abundance during operational years appeared to be within the range of variability established by preoperational monitoring. The operation of New Haven Harbor Station appears to have had no detectable influence on the epibenthic invertebrate community in New Haven Harbor.

OYSTER STUDY

New Haven Harbor has historically served as a natural source of seed oysters (*Crassostrea virginica*) for the Long Island Sound oyster fishery. The environmentally stressed conditions in the harbor necessitate the dredging and transferral of premarketable oysters (10-15 cm) to less impacted areas such as Oyster Bay, Northport Harbor, Peconic Bay and Gardiner's Bay, New York for "self-cleaning" (MacKenzie, 1970). The objectives of oyster studies were to assess effects of generating station operations on oyster growth, mortality and condition index by

comparison of preoperational and operational study data. Condition indices (Galtsoff, 1964), based on a ratio of meat-weight to shell cavity volume were designed to provide an objective means of evaluating oyster readiness for market. This study utilizes the condition index as an additional parameter for evaluation of preoperational and operational differences. In all instances dry weight-condition indices were lower at Harbor Station than at Fort Hale and, in all but one instance (1975), condition indices at Harbor Station were lower than in the oyster stock used for the study. That the difference between experimental stations was a consistent pre- and post-operational phenomenon, suggests that environmental conditions in the inner harbor are generally less favorable to oysters.

Mortality for 1974-1977 was found to be independent of station but dependent on year, indicating that differing environmental conditions at the two experimental sites (including any environmental modification due to the operation of New Haven Harbor Station) had no effect on overall oyster mortality. Significantly higher mortality occurred in 1975 than in any other year tested at both sites and may have been associated with low condition indices observed in the initial oyster stock in 1975. High June and July mortalities give some indication that the oysters purchased were not as healthy as in previous years, and thus were less resistant to disease or predation.

Yearly variation in mean net growth was highly significant; between-station variation was not. At both stations, growth was greatest in 1976 and least in 1977. Patterns of oyster growth by month at Fort Hale and Harbor Station for the years 1973-1977 were not significantly different from each other. Though there was significant variation in mean net growth between years 1973-1977, these results imply that environmental conditions relevant to oyster growth were similar at both stations during pre- and post-operational periods.

The interpretation of these results leads to the conclusion that no effect of the operation of New Haven Harbor Station could be

determined on the growth, mortality or commercial viability (as measured by condition index) of experimental oyster populations within the New Haven Harbor.

TRACE METALS

Trace metals enter New Haven Harbor from the Quinnipiac River, major sewer outfalls located near Long Wharf and near New Haven Harbor Station, as well as from the atmosphere. The dominant sources are the sewer outfalls. New Haven Harbor sediments contain high metal concentrations relative to greater Long Island Sound because of proximity to discharges from several sewage treatment plants. Any contribution from the New Haven Harbor Station discharge, surface runoff or settling pond leachate would be relatively small and be obscured by contributions from the sewer outfalls.

Soft tissue of *Crassostrea virginica* showed lower levels of trace metals in New Haven Harbor oysters than in five other Long Island Harbors studied. Suspension and deposit-feeding molluscs showed slightly higher zinc in New Haven Harbor, but lower copper relative to Long Island Sound. *C. virginica* showed higher concentrations of these metals than other bivalves analyzed including *Mercenaria mercenaria* and *Mytilus edulis*. Trace metal concentrations did not show a pronounced seasonal or spatial pattern in *Mercenaria mercenaria* soft tissue in New Haven Harbor.

Impacts

Impact from New Haven Harbor Station on the trace metal regime in New Haven Harbor, if present at all, is overwhelmed by the ambient long-term trace metal supply and removal patterns.

FINFISH

Although severely polluted, New Haven Harbor supports a diverse and productive ichthyofauna. The harbor provides habitat for many commercially, recreationally and ecologically important fishes, and although it does not support a local commercial finfishery, it does support a healthy local sport fishery. New Haven data indicate that although the harbor serves as a feeding ground and a nursery area, it is not a major spawning ground for finfish (with the possible exception of bay anchovy), and is not dependent on in-harbor spawning for recruitment of finfish eggs, larvae and juveniles. For most species, the harbor is apparently an "importer" of finfish eggs, larvae and possibly juveniles, and an "exporter" of juvenile, pre-adult or adult fish with the result that there is no discrete, resident population of finfishes in New Haven Harbor.

Seventy-four species of finfish were caught using seine, gill net and otter trawl from May 1971 to October 1977. None were unusual occurrences, except for a sturgeon (probably Atlantic) which we believe was of Connecticut River origin. Species which were uncommon in the New Haven collections were either species at the geographic limit of their distribution (e.g., blue runner, smallmouth flounder), non-estuarine species (e.g., haddock, pollock), or species not readily caught by the methods used (lamprey, gobies).

The most common resident fishes of the New Haven shore zone (intertidal and shallow subtidal) were Atlantic silversides, striped killifish and mummichogs. Along with juvenile menhaden which occasionally occurred abundantly in the shore zone, these species comprised over 95% of all fishes seined in New Haven from May 1971 through October 1977. Peaks of shore-zone fish abundance occurred in July or August.

Three classes of demersal fish (sea bottom) can be defined for New Haven Harbor: harbor residents, Long Island Sound residents which utilize the harbor under favorable conditions in spring and fall, and

summer migrants. Two resident species, winter flounder and windowpane, were usually dominant. Other common resident species included cunner, pipefish, tautog and the grubby. Long Island Sound residents which were abundant generally during May and June and October through December included hakes, silver hake, little skates, fourbeard rockling and rock gunnel. Summer migrants frequenting New Haven in abundance included scup, striped and northern searobins, and smooth dogfish. Several flatfishes which were found in New Haven in the summer months included summer flounder, hogchoker, fourspot flounder and Gulf Stream flounder. Overall abundance was highest during the summer nursery period and lowest in midwinter, when only the winter flounder and windowpane were active.

Pelagic fishes (water column) included the winter migrant, Atlantic herring (*Clupea harengus*); anadromous species which, for the most part, utilized New Haven Harbor to a small degree as a pathway to spawning grounds (alewives, bluebacks, shad, smelt); and summer migrants, which included bluefish, weakfish, kingfish, butterfish, menhaden, bay anchovy, mackerel and northern puffer, in addition to the anadromous striped bass. Peak abundance for this assemblage was in midsummer, when weakfish, anchovies, bluefish and menhaden schools were most dense.

Impacts

The operation of a steam electric generating station may directly impact finfish species which frequent the waters used for condenser cooling in three ways: 1) entrainment of planktonic eggs and larvae through the cooling water system; 2) impingement of adults and juveniles on cooling water intake screens; and 3) encounter at all life-history stages with heated waters. Indirect impacts on finfish populations may also occur as a result of direct impacts on other ecosystem components or other finfish.

None of the species collected in the New Haven Harbor samples depends primarily on the Harbor for successful spawning and rearing of young. Consequently, the impact of entrainment on resident species' ecology in New Haven Harbor is moderated by the ability of Long Island Sound to provide recruited larvae and juveniles to replace those destroyed by the generating station. No changes in the adult or juvenile finfish assemblages have been observed which could be attributed to entrainment mortality of ichthyoplankton.

Impingement at the New Haven Harbor Station intake was notable for only two species: a resident species, winter flounder, and a summer migrant, menhaden. Although impingement mortality of approximately 27,000 juvenile winter flounder per year is high compared to other Long Island Sound generating stations, this number is not significant compared to the natural and fishing mortality of the species. High winter flounder impingement rates reflect the large numbers of small winter flounder present in New Haven Harbor. No reduction of the harborwide winter flounder population based on our catch statistics was observed following peak impingement in the winters of 1976 and 1977. Menhaden were impinged in relatively large numbers in the spring and fall of 1976, concurrent with observed mass mortalities of this species suggesting that dead and disabled fish accounted for a large proportion of the observed impingement (D. Damer, pers. obser.); no similar impingement occurred in 1975 or 1977. An occurrence of substantial juvenile weakfish impingement was observed in late November-early December 1977, after completion of the study. For all other species, impingement mortality was small compared to abundance and assumed natural mortality.

Most species including cunner, scup, alewives, bluebacks, shad, mackerel, striped bass and smelt show little or no population change. Other species such as winter flounder, summer flounder, Atlantic herring, menhaden, bay anchovies and weakfish show higher operational than preoperational abundances. The only species with a mean operational abundance below the preoperational range for two or more months was the windowpane in January and February. Unusually cold winters in

the operational years may have caused the slight reduction in abundance observed, or this change may be an artifact of sampling error. There does not appear to be any consistent reduction from preoperational to operational years. We conclude from this result that no impact on the maintenance of a balanced, indigenous assembly of finfish has occurred as a result of New Haven Harbor Station operation. The harbor has continued to support diverse and abundant finfish assemblages which in turn contribute to the recreational and commercial fisheries of Long Island Sound.

AVIFAUNA

New Haven Harbor, though not utilized as a nesting area, is an important foraging and rest area for shorebirds, gulls and waterfowl. It also provides habitat for cormorants, herons, loons, grebes and other waterbirds.

A total of 125 species was observed in New Haven Harbor during the period 1971-1977. Annual numbers of species observed remained fairly constant from 1972 through 1975, but increased substantially in 1976 and during the ten months of 1977. This was due primarily to limited sightings of each of many species of land birds. Increases in numbers of shorebird species observed in 1976 and 1977 are attributed to changes in study personnel.

In each study year, bird counts began increasing in November, and remained at high levels, peaking in February. Numbers then dropped off with the lowest number of birds observed in the period of May through July. Waterfowl numbers were highest in the winter months while shorebird numbers peaked in the summer. Gulls were present in large numbers all year and showed no pattern of fluctuation.

The most abundant species were waterfowl, scaup and black duck. Herring gulls (*Larus argentatus*) were next most abundant, followed

by four shorebirds, semipalmated sandpiper, sanderling, dunlin and black-bellied plover. The western side of the harbor was used extensively by waterfowl, gulls and shorebirds. Substantially fewer numbers and species utilized the eastern side. The distribution of birds within the harbor was related to the availability of feeding and resting habitat which was primarily located at the western side of New Haven Harbor.

Impacts

New Haven Harbor Station has the potential to affect avian populations within New Haven by: 1) inducing avoidance of or attraction to the heated effluent, 2) detrimentally affecting organisms serving as avian food sources, or 3) disturbance by increased ship traffic and interference of the stack and/or transmission lines with flight patterns. Possible impacts were evaluated through inspection of the data prior to and after full-time plant operation commenced.

Lowest numbers of birds were observed in years prior to plant operation, while highest numbers were also observed prior to plant operation as well as after plant operation began. Seasonal abundances have remained consistent during the course of the study. Numbers have generally been highest in late fall and winter, lowest in early to mid-summer and intermediate during other times of the year. This is due to the migratory habits of the birds and is not affected by operation of the New Haven Harbor Station. In addition, comparison of total birds observed in each of three months (January, July and October) throughout the years 1972-1977 shows that, not only have there been fluctuations in numbers, but more birds have been observed during these months since plant operation commenced than prior to plant operation.

The construction and operation of New Haven Harbor Station does not appear to have diminished the harbor's value to birds as a sheltered resting or wintering area and there were no apparent plant effects on food resources available to birds using the harbor.

SUMMATION

Resident populations of many animals and plants in New Haven Harbor, particularly in the inner harbor, exhibit lower abundance and diversity than is characteristic of a healthy estuary in the same biogeographic zone. Pollution-indicator and pollution-resistant species are well represented, although many organisms associated with healthy environmental conditions also persist. Species successional patterns, propagation, and food-chain associations remain characteristic of the Long Island Sound biogeographic zone.

A reduced commercial oyster fishery remains in the outer harbor and adjacent areas of the sound utilizing new cultch to obtain oyster spat spawned in the Morris Creek area. This area is, in fact, reputed to be among the best in Long Island Sound for natural oyster set. Nearly grown oysters are transferred to cleaner areas before marketing. Historical "oyster grounds" in the inner harbor area are now largely defunct due to unacceptable substrate conditions.

Plankton populations in the harbor are, in general, representative of Long Island Sound waters. Phytoplankton densities are generally higher than Sound waters, due to nutrient enrichment from domestic sewage, and blooms are common. Seasonal patterns are consistent from year to year.

New Haven Harbor is inhabited, or visited, by many economically important finfish and shellfish, and remains important to local sport fishermen. The harbor is a spawning ground for anchovies and sand lance: for most other species, early life stages found in the harbor are recruited. Large numbers of juveniles of many species, including winter flounder and weakfish, indicate the importance of the harbor as a consistent seasonal nursery area.

Benthic populations are characterized by opportunistic taxa which display variable seasonal and annual distributions as measured by

abundances and species richness, especially in the highly stressed inner harbor. Despite overall population fluctuations, most dominant species tend to exhibit consistent presence and recurring seasonal trends. An annual subtidal faunal density minimum has regularly occurred in the inner harbor in midsummer, and has been termed the "August effect". This appears to result from the combination of high water temperature, oxygen depletion, and mobilization of toxic substances (e.g., H_2S) from organic-rich, fine-grained substances that particularly characterize the inner harbor. The outer harbor subtidal environment, represented by Morris Cove, has exhibited a more stable infaunal community development in the shallow-water, sandy sediments.

Since 1971, biological monitoring has been carried out during a wide variety of conditions that are likely to be critical for aquatic life, including: low background water quality, periods of intense biological activity, maximum and minimum stratification and circulation. Several species of finfish and shellfish were identified as particularly subject to impingement; however, for the finfish and mantis shrimp, such impacts have been accompanied by detectable increases in abundance. The combined presence of dominant species and the phenomenon of repeated consistent trends over the long-term period studied enable preoperational characteristics of the harbor to be identified despite variability.

Comparison of preoperational and operational periods for all assemblages monitored with respect to species composition, abundance, diversity, and spatial and temporal distribution indicates no discernible plant impact on the biota of New Haven Harbor.

